NASA CONTRACTOR REPORT

NASA CR-21

N64-16534

CODE-1

NASA CR-21

83p.

HUMAN TRACKING PERFORMANCE UNDER TRANSVERSE ACCELERATIONS

by L. G. Summers and A. A. Burrows

Prepared under Contract NASr-68 *by*
DOUGLAS AIRCRAFT COMPANY, INC.
Long Beach, California
for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1964

(NASA CR-21) OTS: $2.25

HUMAN TRACKING PERFORMANCE UNDER TRANSVERSE ACCELERATIONS

By L. G. Summers and A. A. Burrows

1, Feb. 1964 83 p refs

Prepared under Contract NASr-68 by

DOUGLAS AIRCRAFT COMPANY, INC.

Long Beach, California

OTS 022

(NASA contract NASr-68)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce, Washington, D. C. 20230 -- Price $2.25

TABLE OF CONTENTS

		Page
APPENDIXES		

FIGURES

TABLES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACTOR REPORT CR-21

HUMAN TRACKING PERFORMANCE UNDER TRANSVERSE ACCELERATIONS

By

L. G. Summers and A. A. Burrows

16534

SUMMARY

Human performance was measured for control display parameters during positive and negative transverse acceleration ("eyeballs in" and "eyeballs out"). Five subjects were given a compensatory tracking task in pitch and roll using a two-axis side arm controller and a CRT attitude display with a moving horizon. Three acceleration levels were used, each consisting of a two minute duration.

Performance was measured by the integral of absolute error in both the pitch and roll axes. There was a decrement in performance in the pitch axis with increased acceleration but differences in the roll axis were shown only for one analysis model of two. No differences were recorded in performance due to direction of the acceleration. Physical control characteristics, such as pre-load and spring constant, did not affect performance or interact with acceleration. Aircraft dynamics affected performance but did not interact with acceleration.

Author

Changing control sensitivity did not affect measured performance. Visual error feedback, which averaged performance over a period of time, improved performance in pitch and degraded performance in roll.

Subjective evaluation by the use of pilot rating scores differed from the tracking error scores only in that subjects rated performance at all acceleration levels the same whereas error scores indicated degradation at higher accelerations. Subjective ratings of control sensitivity generally agreed with tracking error scores.

INTRODUCTION

Many studies on performance under acceleration have been concerned with reaction time and simple perceptual-motor tasks. It has been shown that there is an increase in reaction time for both audio and visual signals with an increase in positive and transverse accelerations (Refs. 1, 2, 3, 4 and 5). The major reason for this delay in reaction time is thought to be due in part to the increase in muscular load for the response. In more complex tasks, involving perceptual-motor skills, the same effect has been noted. It was found that there was a differential effect, dependent upon the direction of acceleration (Refs. 6 and 7).

Studies on continuous tracking performance under acceleration load have shown decrements in performance (Refs. 8, 9, 10 and 11). That the effects are complex is exemplified by work on static and dynamic simulations (Ref. 12), where subjects performed better at moderately high accelerations (4-6g) than under static conditions. At higher accelerations the trend appears to change. Kaehler (Ref. 13), investigated the effect of an exponential time lag of the control while the subject was exposed to transverse acceleration. He found that for the roll modes there was an interaction between the level of acceleration and time lag.

The major effect of lower levels of positive transverse acceleration on human performance appears to be in the motor functions, while there seems to be little or no effect on visual and auditory senses or in cognitive processes. This motor effect might be due to the effects of a force gradient against which the muscle has to act, tending to affect the proprioceptive or "feel" sensing of the muscle. Error and response time might logically be expected to increase for this hypothesis. The purpose of the present study was to extend the range of data derived from previous research in these areas.

SYMBOLS

$\theta(s)/\delta_e(s)$ = transfer function of pitch angle to elevator deflection

$\phi(s)/\delta_a(s)$ = transfer function of roll angle to aileron deflection

$M_{\delta e}$ = pitch acceleration developed per unit control deflection in $\frac{rad/sec^2}{rad}$

ω_n = longitudinal undamped short period natural frequency in rad/sec

ζ = longitudinal short period damping ratio

$\phi(s)$ = roll deflection term for transform equation

$\delta_a(s)$ = aileron deflection term for transform equation

$L_{\delta a}$ = roll acceleration developed per unit control deflection in $\frac{rad/sec^2}{rad}$

τ = roll mode time constant

$\theta(s)$ = pitch deflection term for transform equation

$\delta_e(s)$ = elevator deflection term for transform equation

e/e_i = transfer function of the error feedback system

K_1 = scale factor associated with the visual error feedback signal

T = RC time constant of the visual error feedback circuit

s = Laplace operator

e = displacement tracking error

t = time

r_s = Spearman Rank Correlation Coefficient

χ_r^2 = Chi-square test; Friedman Two-Way Analysis of Variance

EXPERIMENTAL OBJECTIVE

The overall program consisted of four experiments designed to study the effects of transverse acceleration, and other variables, on human tracking performance. In all of the experiments transverse acceleration was applied in a front-to-back (eye-balls-in) and in a back-to-front (eye-balls-out) direction. In each experiment two levels of acceleration were used; 4g and 6g, as well as a static condition which was designated as a "control" condition in terms of experimental design. Additional variables introduced in specific experiments were:

1) Control stick preload
2) Control stick spring constant (force-displacement gradient
3) Vehicle dynamics
4) Control stick sensitivity
5) Presence or absence of error feedback information

APPARATUS

Centrifuge

The Human Centrifuge at the University of Southern California was used to apply transverse acceleration loads of 4 and 6g in a uniform manner over the subject's torso, Fig. 1A. The time from onset of acceleration to peak was 11.3 seconds for the 4g runs and 12.8 seconds for the 6g exposures. Duration at peak acceleration was 120 seconds in both cases. The deceleration time was 7 seconds for the 4g runs and 9 seconds for the 6g exposures. An acceleration time history was recorded from an accelerometer mounted adjacent to the subject's seat.

Restraint System

The seat and the restraint suit used for these experiments were designed and developed by the Ames Research Center of the National Aeronautics and Space Administration. The complete restraint system is shown in Fig. 1B. The restraint suit consisted of a contoured back-frame with leg rests attached to the back frame by seat straps. The back frame and the leg rests could be mounted and removed from the seat frame by lug inserts with pin locks. Air bladders inserted between the seat frame and the occupant could be pressurized for the comfort of the subject. The bladders also served to tighten the subject against a restraint vest that was buckled to the back of the frame.

The thighs were zipped into leggings attached to the leg rests. The seat frame had adjustable foot rests and arm rests for individual comfort. A helmet with custom fitted facial inserts were used to provide head restraint. The helmet was attached to the seat frame by a lug insert with a pin lock. The helmet was obtained from Protection, Inc., Los Angeles, California and is designated as a Supertopex helmet. An anti-g suit was also worn on all runs but was operational only on the Eye-Balls-Out (EBO) runs.

Additional restraint was provided for the arms, legs and kneecaps under EBO conditions. The leg restraint included knit-stretch pants and the legs and feet were wrapped with elastic bandages to minimize pooling of the blood in the lower extremities. The forearms and hands were wrapped with non-elastic bandages and rubber gloves were worn so as to minimize pooling in the upper extremities. The additional provisions to minimize blood pooling were only provided in the EBO runs because the direction of acceleration in the EBI conditions inherently minimized the occurrence of pooling.

Display

The display consisted of a standard cathode ray tube with a fixed aircraft symbol and a moving horizon, suitable for a compensatory control task wherein the display had two degrees of freedom, pitch and roll. (Fig. 2).

The tube diameter was five inches. A one cm. displacement in pitch (display) was equal to five degrees of vehicle pitch error. A one degree roll deviation on the display was equal to one degree of vehicle roll error. For additional pitch-error feedback, a circle was superimposed on the horizon display which increased in size with increasing error and decreased (toward the center of the display) with decreasing error. (Fig.3)

The left-hand control consisted of a fixed stick grip with an abort button. The right-hand control (Fig. 4) was a two-degree-of-freedom controller with a 1 1/2 inch diameter spherical grip. The lever arm for this controller, for both pitch and roll was five inches. The right hand control was used by the subject in performance of the tracking task. This control was dynamically balanced for acceleration loads perpendicular to its longitudinal axis. Limited "feel" characteristics were provided by two bungees on precision lever arms. The length of the lever arms could be changed in order to vary the spring constant, while stick detent or breakout force could be varied by changing the pretension on the bungee. These parameters could be varied independently. Force-displacement data showing the conditions used in the experiment may be found in Figures 5A and 5B.

Two values of control stick sensitivity used were designated 1/1 and 2/1. These notations are ratios of angular control stick displacement to control surface displacement and apply to both pitch and roll modes.

<u>Task</u>

The tracking task was compensatory tracking in pitch and roll with simplified uncoupled vehicle dynamics:

$$\frac{\theta(s)}{\delta_e(s)} = \frac{M_{\delta_e}/\omega_n^2}{s^2/\omega_n^2 + 2\zeta s/\omega_n + 1}$$

for longitudinal dynamics where $M_{\delta e}$ is the pitch acceleration developed per unit control deflection, ω_n is the short-period frequency and ζ is the damping ratio and

$$\frac{\phi(s)}{\delta_a(s)} = \frac{L_{\delta a}\tau}{s(\tau s+1)}$$

for lateral dynamics where $L_{\delta a}$ is the roll acceleration developed per unit control deflection and τ is the roll damping as a time constant.

The command signal (forcing function) for tracking was a Gaussian-distributed random noise signal whose power spectrum characteristics were flat from 0 to 0.25 cps with a 12db drop per octave thereafter. A separate signal was used for the pitch and roll axes. A maximum deflection of ± 15° was used for pitch and ± 10° was used for roll. The pitch and roll input signals to the analog computer were provided by a two channel FM tape recorder play-back using previously recorded tape. The data from the runs were recorded on two seven-channel FM tape recorders.

The visual error feedback signal was derived by the use of the first order transfer function:

$$\frac{e_o}{e_i} = \frac{K_1}{1+Ts}$$

where K_1 is a scale factor and T is the RC time constant. The value of T was 2 seconds. Feeding the absolute value of the pitch error into this function gave the average value of the absolute error over a 2 second period. This value was scaled to increase and decrease the diameter of the circle on the display.

Measures

A continuous recording was made on FM tape of the following parameters during all tracking tasks:

1) Command signal, pitch
2) Command signal, roll
3) Control stick position, pitch
4) Control stick position, roll
5) Vehicle position (angular), pitch
6) Vehicle position (angular), roll
7) Angular error, pitch
8) Angular error, roll
9) g magnitude
10) EKG (electrocardiograph)

Silver electrodes, 1/2 inch in diameter and 3 mils in thickness were used to record the electrocardiograph. The electrodes were cemented to the subject's skin with Eastman 910 cement. They were placed inferior at the angle of the left and right tenth ribs and the xiphoid process of the sternum (breastbone).

In the third and fourth experiments, the subjects were asked to rate their own performance during each tracking task. The subjects recorded their responses on a 10 point rating scale (Appendix 6) originally devised by Cooper (Ref. 15) for the use of pilots in rating the handling qualities of aircraft.

EXPERIMENTAL DESIGN

Each subject received two experimental runs per day in which each run consisted of four successive two minute tracking periods; a static condition (centrifuge stationary), 4 g acceleration condition, a static condition and a 6 g acceleration condition. The average time interval between tracking periods was approximately three minutes. The two experimental runs that a subject received during a day differed with respect to direction of acceleration, i.e., if the first run was "EBO" the second run would be "EBI" and vice versa. The time interval between runs ranged from 2 to 4 hours. The direction of acceleration was varied for each subject on successive days in order to randomize the direction of acceleration with respect to time of day.

This design allowed for repetition of the static tracking period where only the restraint system was different for the "EBI" and "EBO" directions.

Parameters which were used as independent variables in the overall research program were as follows:

1) Acceleration direction (EBO and EBI)
2) Acceleration magnitude (static, 4g and 6g)
3) Control stick preload (0.2 and 0.5 lbs)
4) Control stick force-displacement gradient (0.2 and 0.05 lbs/degree)
5) Control stick sensitivity (1/1 and 2/1)

6) Vehicle dynamics ("good" and "bad")

7) Additional pitch error feedback (absent or present). For control stick sensitivity, the notation 1/1 and 2/1 represent ratios of angular control stick to control surface displacements. This applies to both the pitch and roll modes.

With reference to vehicle dynamics the following definitions apply:

1) For "good" dynamics:

a) $M_{\delta e}/\omega_n^2 = 2/3\,\pi$

b) $\omega_n = \pi$

c) $\zeta = 0.5$ for longitudinal control

d) $L_{\delta a} = 6.0$

e) $\tau = 0.5$ for lateral control

2) For "bad" dynamics:

a) $M_{\delta e}/\omega_n^2 = 2/3\,\pi$

b) $\omega_n = \pi$ rad./sec.

c) $\zeta = 0.06$ for longitudinal control

d) $L_{\delta a} = 1.0$

e) $\tau = 3.0$ for lateral control

For purposes of discussion, the overall research program may be described as consisting of a standard control condition and four experiments. The standard control condition was administered prior to experiment number one, and again, upon completion of experiment number four. The data derived from the standard control condition was used to determine the presence of "learning" effects. This was performed by comparing performance for the two separate administrations of this condition. The standard control condition may be defined as follows:

1) Acceleration direction (EBO and EBI)
2) Acceleration magnitude (static, 4g and 6g)
3) Control stick preload (0.2 lbs)
4) Control stick force-displacement gradient (0.2 lbs/degree)
5) Control stick sensitivity (1/1)
6) Vehicle dynamics ("good")
7) Additional pitch error feedback (absent)

The four experimental programs are identified as follows:

Experiment No. 1

1) Acceleration direction (EBO and EBI)
2) Acceleration magnitude (static, 4 g and 6 g)
3) Control stick preload (0.2 lbs and 0.5 lbs)

Total treatment combinations = 2x3x2 = 12

Experiment No. 2

1) Acceleration direction (EBO and EBI)
2) Acceleration magnitude (static, 4 g and 6 g)
3) Control stick force-displacement gradient (0.05 and 0.2 lbs/degree)

Total treatment combinations = 2x3x2 = 12

Experiment No. 3

1) Acceleration direction (EBO and EBI)
2) Acceleration magnitude (static, 4 g and 6 g)

3) Control stick sensitivity (1/1 and 2/1)

4) Vehicle dynamics ("good" and "bad")

Total treatment combinations 2x3x2x2 = 24

Experiment No. 4

1) Acceleration direction (EBO and EBI)

2) Acceleration magnitude (static, 4 g and 6 g)

3) Additional pitch error feedback (absent and present)

Total treatment combinations 2x3x2 = 12

Parameters not specifically listed in the four experiments, but identified in the definition of standard control condition, were treated as "control" variables whose values may be determined by reference to the definition previously given for the standard control condition.

Since the same control condition was used for purposes of data analysis in all four experiments, it was not actually repeated during these four phases. As noted earlier, it was administered prior to Experiment No. 1 and after Experiment No. 4. This resulted in a total of 48 treatment combinations or runs for each subject in order to complete the entire program.

The sequence of presentation for the overall program was as follows:

1) Standard Control Condition (Initial)

2) Experiments 1 thru 4, in order

3) Standard Control Condition (Final)

A total of six subjects were used, where four of these served as within-cell variance for the first two experiments and five of the six subjects were used as within cell variance for the third and fourth experiments. Two of the subjects were university students with prior centrifuge experience, but no actual flight experience. The four remaining subjects were all qualified pilots with three of the group currently performing duties as test pilots. Only one of the pilots had prior centrifuge experience.

For purposes of test procedure the subjects were treated as a random variable while the other variables were treated as fixed variables. Since a question could be raised regarding the normalcy of the sub-samples (i.e. subjects) in the cells of the simple factorial design, a second analysis was performed using a treatments-by-subjects design and is presented in Tables 4C, 4D and 5B. The results obtained in the second analysis did not appear to differ sufficiently, in terms of statistical or practical significance, to warrant special comment.

Only three of the six subjects served throughout the entire program. Scheduling problems with reference to the simultaneous availability of the individual subject prevented the remaining three subjects from participating in the total program. In any event, the data from subjects 1, 2, 3 and 5 were used for purposes of analysis in experiments 1 and 2. Subjects 2 through 6 provided the data for the third and fourth experiments.

RESULTS

Performance Criteria

Tracking task performance was measured by taking the averaged integral of absolute error sampled at five second intervals over the two minute tracking period. This is expressed as follows:

$$\text{Average Error} = \frac{1}{n} \sum \frac{\int_{t_1}^{t_2} |e|\, dt}{T}$$

where t_1 to t_2 was 0 to 5 seconds and T was 5 seconds. Pitch and roll error were analyzed separately by performing an analysis of variance.

The variation in performance as a function of acceleration magnitude and direction for the control condition is shown in Figure 6. The analysis of variance of this data is shown in Table 1, where a significant difference in performance is noted for the pitch mode due to acceleration magnitude. All other comparisons were not significant.

To determine the existence of "learning effects" over the entire experimental program, performance was compared for the first and last administrations of the control condition. (i.e., the first two and last two runs) Variations in performance due to learning are shown for pitch error only in Table 2 and Figure 7. The analysis of variance (Table 2) shows an almost significant difference in performance due to acceleration and a definitely significant difference attributable to learning effects. The interaction however, was not significant.

Variations in performance due to control stick preload were examined for the pitch mode data. The analysis of variance data is shown in Table 3 where it may be noted that performance did not differ significantly as a function of the two values of preload used. The interaction between preload and acceleration (direction and magnitude) was also not significant.

The same type of analysis was performed to test for performance differences due to the spring constant variable. Again, there were no significant differences due to the spring constant variable per se, or to its interaction with acceleration.

Aircraft dynamics and control sensitivity were studied simultaneously against acceleration, which led to four conditions: the standard control; bad aircraft dynamics; 2/1 control sensitivity ratio and bad dynamics; and a 2/1 control sensitivity ratio. The results of these tests are shown in Table 4A and 4B and Figures 8A and 8B.

These results show a significant change in error with acceleration in pitch and with bad dynamics in pitch and roll. However, there was no change in error with control sensitivity or any interactions when subjects are treated as within-cell variance. When a treatment by subjects design is used as shown in Tables 4C and 4D, the aircraft dynamics x control sensitivity interaction becomes significant in pitch. The subjects x acceleration and the subjects x aircraft dynamics interaction terms also become significant in pitch. In roll only the second order interaction, aircraft dynamics x control sensitivity x subjects, is significant in addition to the significance of the within cell design.

The results of adding visual feedback of pitch error are given and shown in Table 5A and Figure 9. These results show a significant lowering of pitch error, however the roll error increases when the subjects are treated as within cell variance.

For the treatment by subjects analysis shown in Table 5B, the visual error feedback is significant in both pitch and roll. However, in pitch the subject interaction with acceleration decreases significant differences due to acceleration. In roll the subject interaction with visual error feedback lowers the significance level for visual error feedback.

Subjective Criteria

The pilot ratings were used as a subjective measure to enable the subject to evaluate his performance for the particular experimental task. The analysis of these results became more difficult in that each subject adopted a different scale of measure. This is shown by the means and variances of each subject as compared to the total mean and variance. These data are presented in Table 6A. The means and the variances for subjects did not differ significantly except for subject no. 5. For testing differences between conditions a non-parametric rank test was used since it was felt that the subjective rating scale would not satisfy all conditions for a parametric test.

The effect of acceleration level and direction was evaluated by the Friedman Two-Way Analysis of Variance by Ranks (Ref. 16). For pitch ratings this test gave a χ_r^2 value of 1.37 with five degrees of freedom. (Appendix 3b). For roll ratings, the obtained χ_r^2 was 1.05 with five degrees of freedom (Appendix 3b). These values indicate that the subjects were unable to evaluate a difference in their pitch performance with acceleration direction or magnitude.

The effects of aircraft dynamics, control sensitivity and visual feedback were tested against the control condition by the Wilcoxon matched-pairs signed-ranks test (Ref. 16). These tests showed a significant improvement for the control sensitivity ratio at the 0.05 level and a significant degradation in the "bad dynamics", at the 0.01 level, for both pitch and roll. No significant difference occurred with the visual error feedback condition.

The subjective rating data was further evaluated by the use of a nonparametric correlation test (Table 6B). This evaluation was performed on an individual basis so as to determine the presence or absence of subjective consistency across the various experimental conditions. In performing this analysis, each subject's ratings were compared to his tracking performance for pitch and roll separately. The obtained correlation coefficients, as shown in Table 6B, were all positive and significant at the .05 or .01 level except for two cases.

Heart Rate

The electrocardiograph was analysed for heart rate of the subjects. The average heart rates of all conditions are shown in Figure 10 for static, 4 g and 6 g acceleration levels and for EBI and EBO acceleration direction. This shows that the heart rates are high for the static condition (possibly due to anticipation) and increased in the acceleration conditions. However, the only statistically significant difference occurred between the static EBI run and the acceleration runs.

DISCUSSION

Performance Criteria

The results on performance error indicate that mainly pitch or longitudinal error was affected by acceleration. This could be explained by the earlier hypothesis that the effect of acceleration is only on the motor performance, since for pitch, tracking arm movements are required in the direction of acceleration. This would indicate that the subject either over-compensates or under-compensates movement of the stick depending on whether he is moving in the same direction of the acceleration or 180° out of phase.

There was also a difference in pitch error between the static conditions for EBI acceleration and EBO acceleration. This difference becomes more prominent if the samples are pooled for the conditions where no significant difference occurred in order to increase the sample size. These results are shown in Table 7 and Figure 11. Although the trend in roll is in the expected direction it will be noted from the analysis of variance (Table 7) that the difference is not significant. This difference appears to be due to the additional restraint on the hand for the EBO condition. If this difference is cancelled for the acceleration conditions as a standard error, it can be seen that there is no difference between the two directions.

The ability of the subject to track under acceleration did not appear to hinder his performance sufficiently in comparison with the larger amount of performance error with the bad aircraft dynamics. However, if the error were due to motor performance, then the error would have increased with brief periods of acceleration.

For the values used in the physical control characteristics and control sensitivity, there was no change in performance or any interaction with acceleration. Also, with the aircraft dynamics no interaction with acceleration occurred.

The visual feedback of pitch error did improve the pitch performance enabling the subject to maintain a constant level of performance. However, in improving their pitch performance the subjects tended to let the roll error increase.

Subjective Criteria

Of the five separate analyses performed involving pilot opinion data, certain conclusions may be tentatively drawn at this time. The rating data per se failed to discriminate differences due to acceleration, direction or magnitude (Appendix 3b), or that due to the presence or absence of visual error feedback (Appendix 3c). Under these same conditions the analysis of performance measures revealed significant differences in tracking performance.

Analysis of the rating data for the control sensitivity variable and for the aircraft dynamics variable, did reveal a systematic trend (Table 3c). For the two values of control sensitivity, a significant difference in pilot ratings was obtained. The analysis of variance data in general, did not support this finding (Tables 4A, B, C, D). The pilot ratings for aircraft dynamics (good versus bad) were significant for both pitch and roll (Table 3c). This finding received support from the tracking performance data in that it produced significant differences in all cases.

The correlational analysis of the pilot rating data tended to provide some support of its functional value. (Table 6B). In this case the individual's rating scale data was directly correlated with his own tracking performance for each condition. In addition, a distinction was made between pitch and roll. As shown in Table 6B, eight of the ten values so computed were found to be significant at either the 0.05 or 0.01 level. In spite of the positive nature of these latter findings, there is a need to interpret them cautiously in the context of this experiment. This is certainly indicated by the overall lack of systematic results discussed earlier.

Rating scales may thus be somewhat limited in their application if the subject, especially under conditions of stress, is unable to systematically discriminate differences in his actual performance and behavior in a consistent manner. This does not imply that objective performance measures should be used to the exclusion of rating scale data. There are many research situations dealing with aircraft handling qualities for example, wherein rating scale data is the only means of evaluation. In addition, rating scale data is often useful when taken simultaneously with objective performance measures. Human adaptability over a fairly wide range of conditions sometimes results in objective performance measures which fail to discriminate optimum values for physical (vehicle) parameters. This ability to maintain a relatively constant performance is recognized as being a major reason for placing a pilot in the system. Under these conditions however, rating scale data may provide the only information for making design decisions.

Future research in this area might logically seek to provide additional information on the relative sensitivity of rating scale data as compared to objective measures of performance. This should be performed under various stress conditions such as acceleration, temperature, noise, vibration and hypoxia. Various combinations of the above taken with more complex pilot tasks might more clearly define the relative contributions of rating scale data and objective performance measures.

SEPTEMBER 22, 1962

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

(1) Significant differences in motor performance were observed when the motor movements were in the same plane as the acceleration forces.

(2) There appeared to be no difference in performance between the EBI direction of acceleration and the EBO direction.

(3) Subjective evaluation by the use of pilot-rating scales was not as sensitive as measured error scores and appeared to lead to erroneous conclusions under acceleration.

(4) Visual feedback of pitch error improved pitch performance and also interacted with roll performance.

(5) There was no interaction between acceleration and the control characteristics, aircraft dynamics or control sensitivity values used in these experiments.

REFERENCES

1. Brown, J. L., and Burke, R. E.: The Effect of Positive Acceleration on Visual Reaction Time. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa., NADC-MA-5712, Aug. 1957.

2. Burmeister, H.: Untersuchungen Über Änderungen der Optischen Reaktionszeit des Menschen Beim Einwirken Hoher Fliehkräfte (Measurement of Optical Reaction Time in Both Positive and Transverse G.) (In German), Luftfahrtmedizin, vol. 3, Band 4, 1939, pp. 277-284.

3. Canfield, A. A., Comrey, A. L., and Wilson, R. C.: A Study of Reaction Time to Light and Sound as Related to Increased Positive Radial Acceleration. J. Avia. Med., vol. 20, no. 5, Oct. 1949, pp. 350-355.

4. Canfield, A. A.: The Influence of Positive G on Reaction Time. Amer. Psychologist, vol. 5, no. 7, July 1950, p. 362 (Abstract only).

5. Seckel, E., and Hall, I. A. M.: Human Pilot Dynamic Response in Flight and Simulator. Wright Air Development Center TR 57-520, Aug. 1958.

6. Brown, J. L., and Lechner, M.: Acceleration and Human Performance: A Survey of Research. J. Avia. Med., vol. 27, no. 1, Feb. 1956, pp. 32-49.

7. Canfield, A. A.: The Influence of Increased Positive G on Reaching Movements. J. Appl. Psychol., vol. 37, no. 3, June 1953, pp. 230-235.

8. Brown, J. L., and Collins, C. C.: Air-To-Air Tracking During Closed-Loop Centrifuge Operation. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa., NADC-MA-5803, Mar. 1958.

9. Fletcher, D. E., Collins, C. C., and Brown, J. L.: The Effects of Positive Acceleration Upon the Performance of an Air-To-Air Tracking Task. Aviation Medical Acceleration Lab., Naval Air Development Center, Johnsville, Pa., NADC-MA-5807, 1958.

10. Kaehler, R. C.: Human Pilot Performance During Boost and Atmosphere Re-entry. Aerospace Med., vol. 30, no. 7, July 1959, pp. 481-486.

11. Creer, B. Y., Smedal, H. A., and Wingrove, R. C.: Centrifuge Study of Pilot Tolerance to Acceleration and the Effects of Acceleration on Pilot Performance. NASA TN D-337, Nov. 1960.

12. Chambers, R. M., and Doerfel, H. V.: Closed-Loop Centrifuge Simulation of Space Vehicle Performance. Paper presented at ARS semi-annual meeting, June 8-11, 1959, San Diego, Calif., ARS paper no. 807-59.

13. Kaehler, R. C.: The Effects of Transverse Accelerations and Exponential Time-Lag Constants on Compensatory Tracking Performance. Aeronautical Systems Div. TR 61-457, Sept. 1961.

14. Rathert, G. A., Jr., Creer, B. Y., and Douvillier, J. G., Jr.,: Use of Flight Simulators for Pilot-Control Problems. NASA Memorandum 3-6-59A, Feb. 1959.

15. Cooper, G. E.: Understanding and Interpreting Pilot Opinion. Aero. Eng. Rev., vol. 16, no. 3, Mar. 1957, pp. 47-51, 56.

16. Siegel, S.: Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Co., New York, 1956.

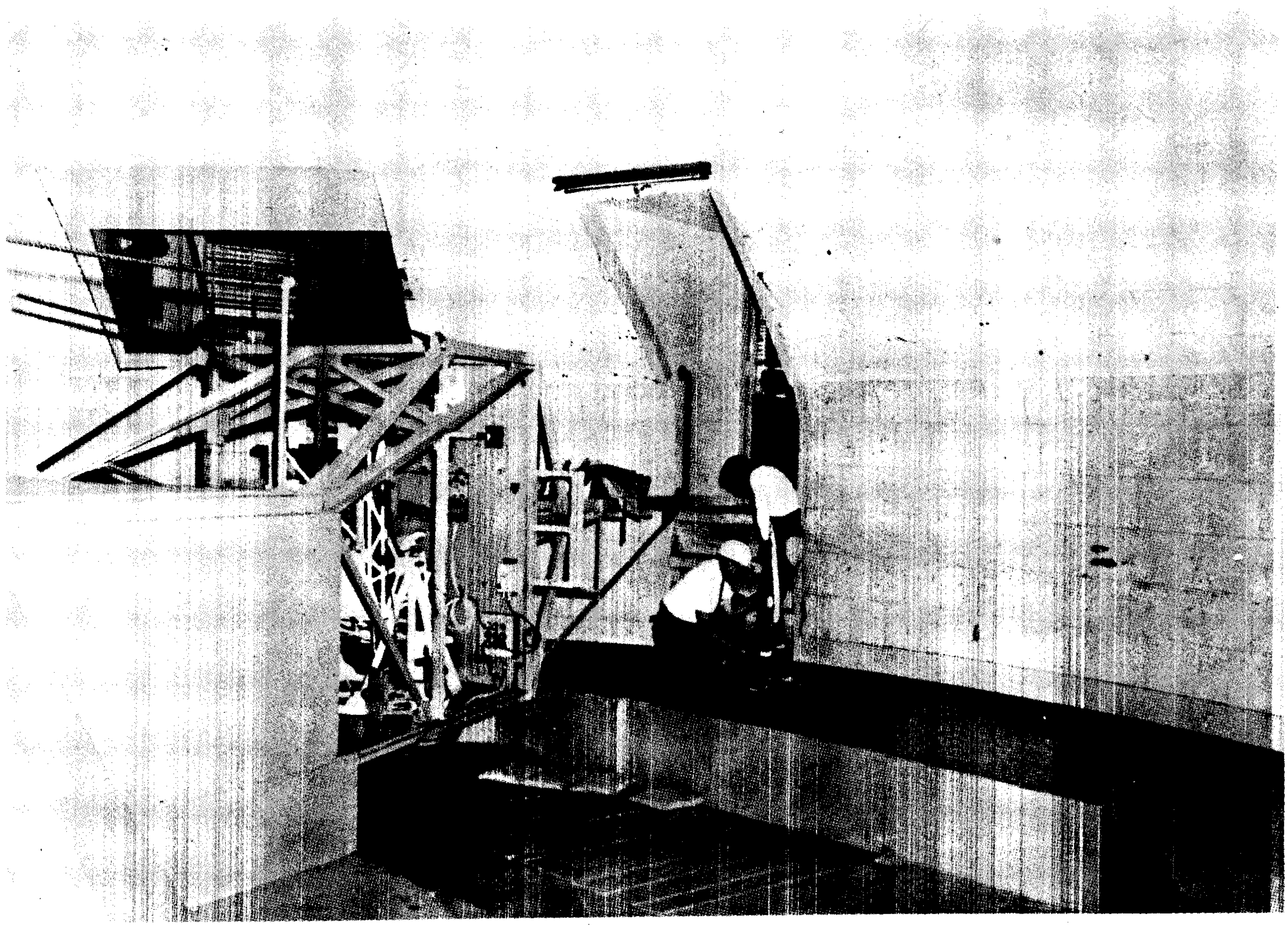


FIGURE 1A. UNIVERSITY OF SOUTHERN CALIFORNIA HUMAN CENTRIFUGE

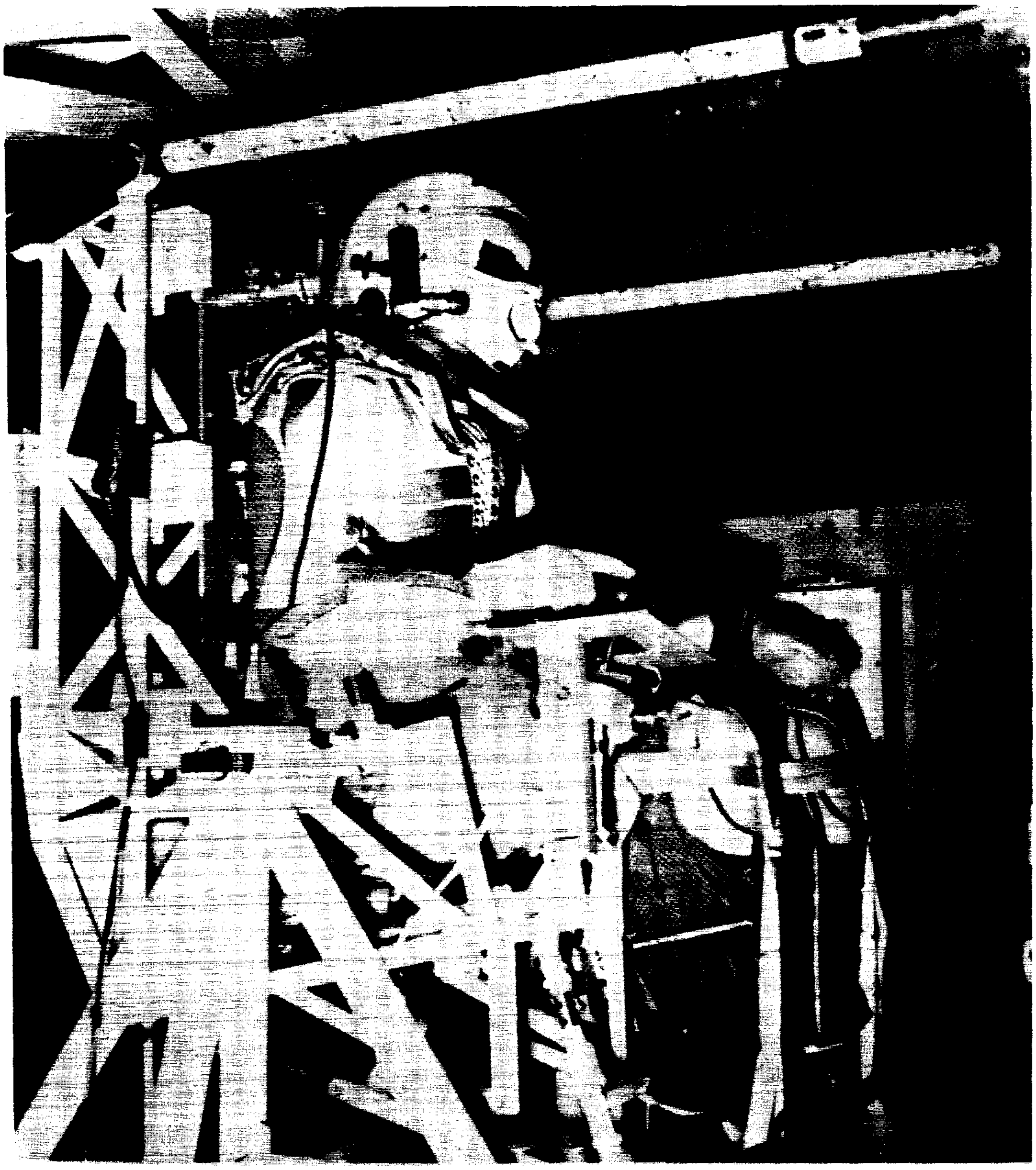


FIGURE 1B. SUBJECT IN RESTRAINT SYSTEM (EBO)

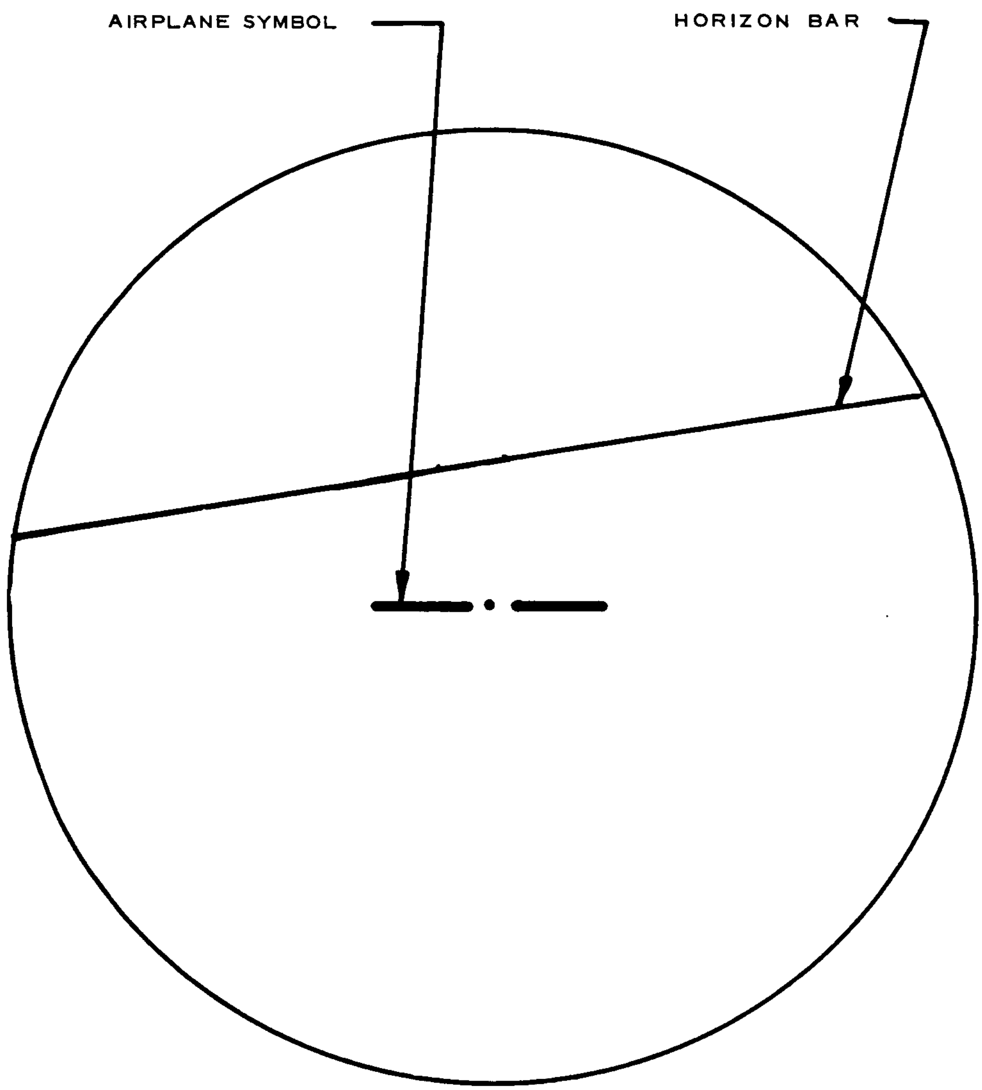


FIGURE 2. CRT DISPLAY USED, SHOWING NOSE-DOWN, RIGHT BANK

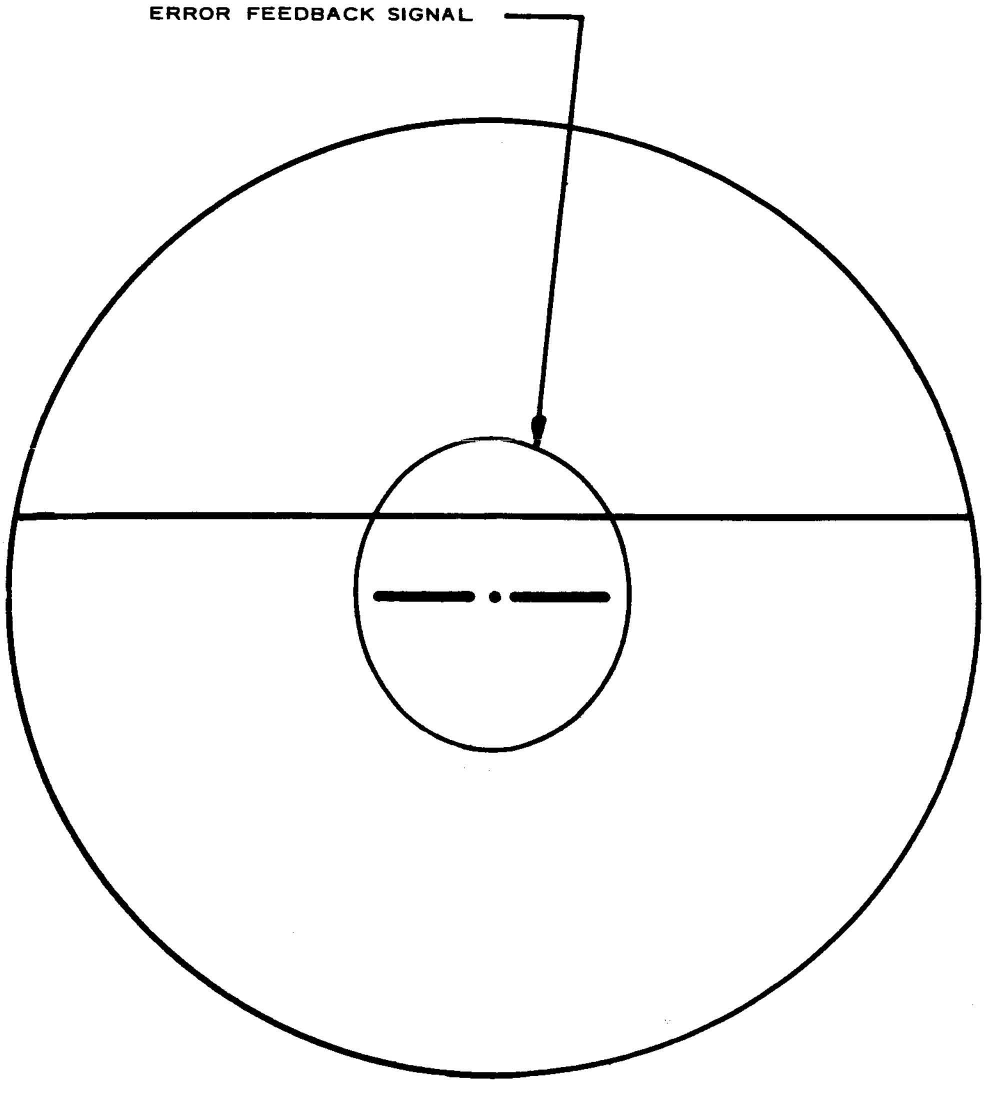


FIGURE 3. CRT DISPLAY USED, SHOWING ERROR FEEDBACK SIGNAL

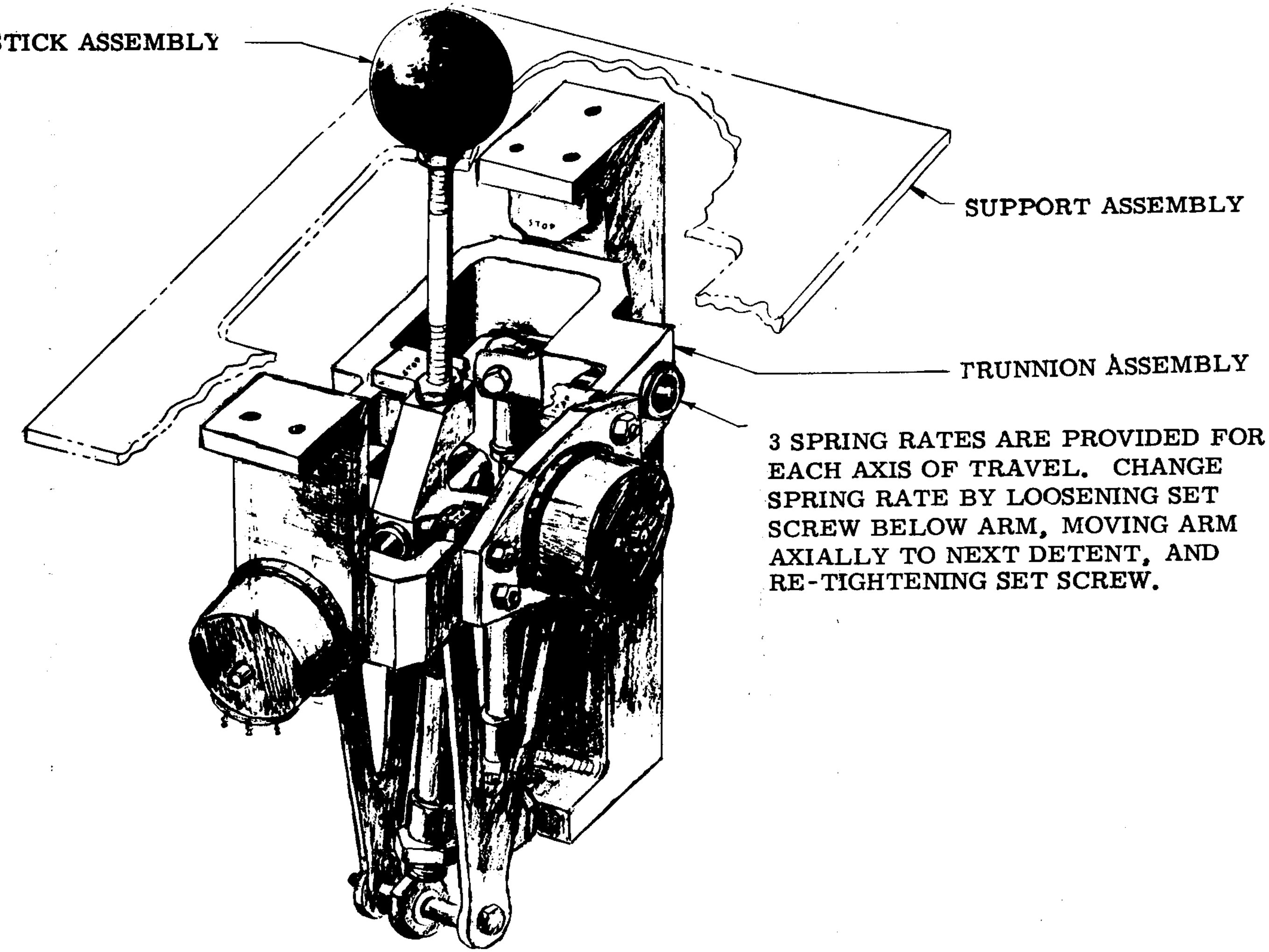


FIGURE 4. SIDE STICK CONTROL

Note: Add stops as shown on assembly to limit stick throw to $\pm 30^{\circ}$ for each axis of travel.

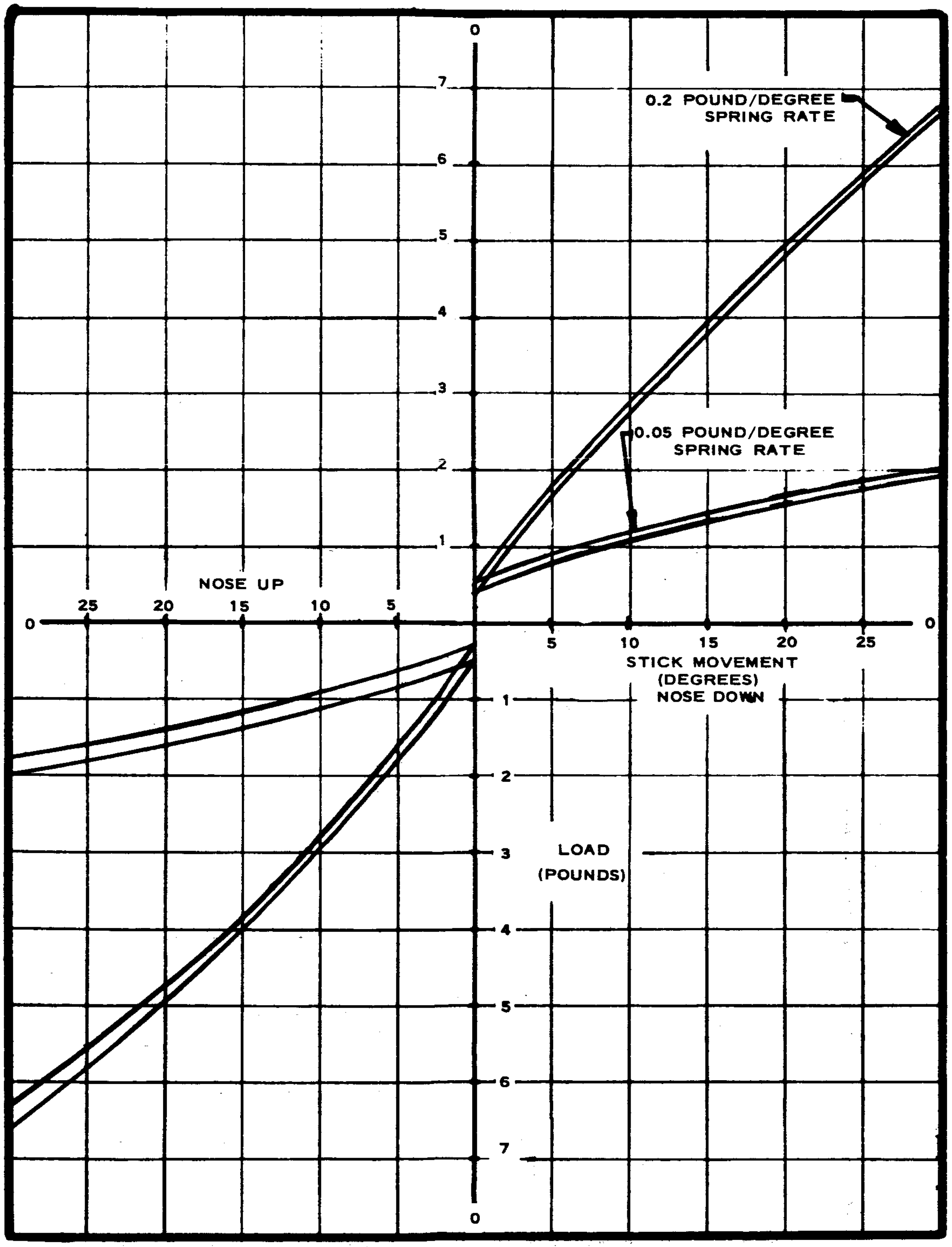


FIGURE 5A. CONTROL STICK FORCE-DISPLACEMENT CHARACTERISTICS (PITCH)

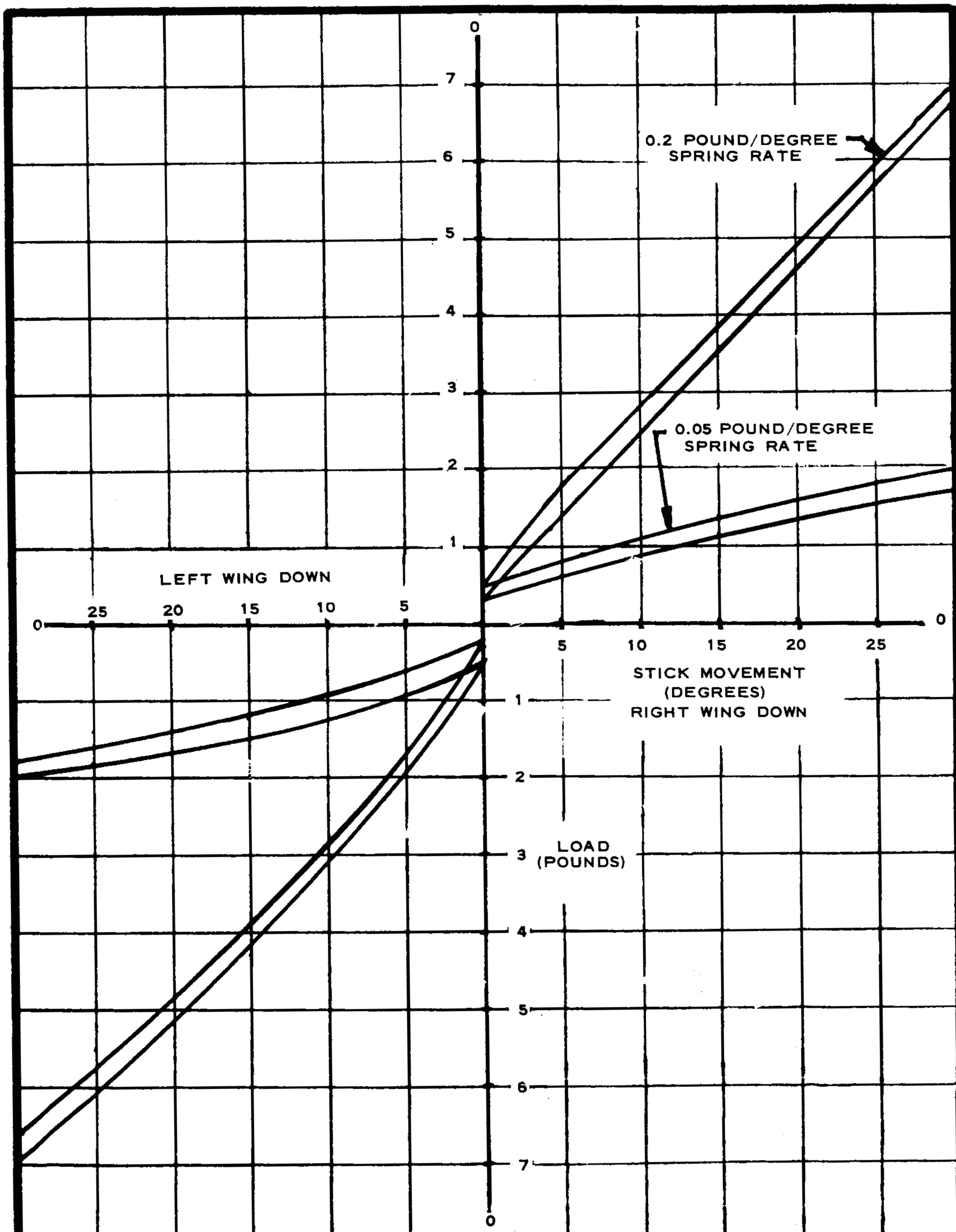


FIGURE 5B. CONTROL STICK FORCE — DISPLACEMENT CHARACTERISTICS (ROLL)

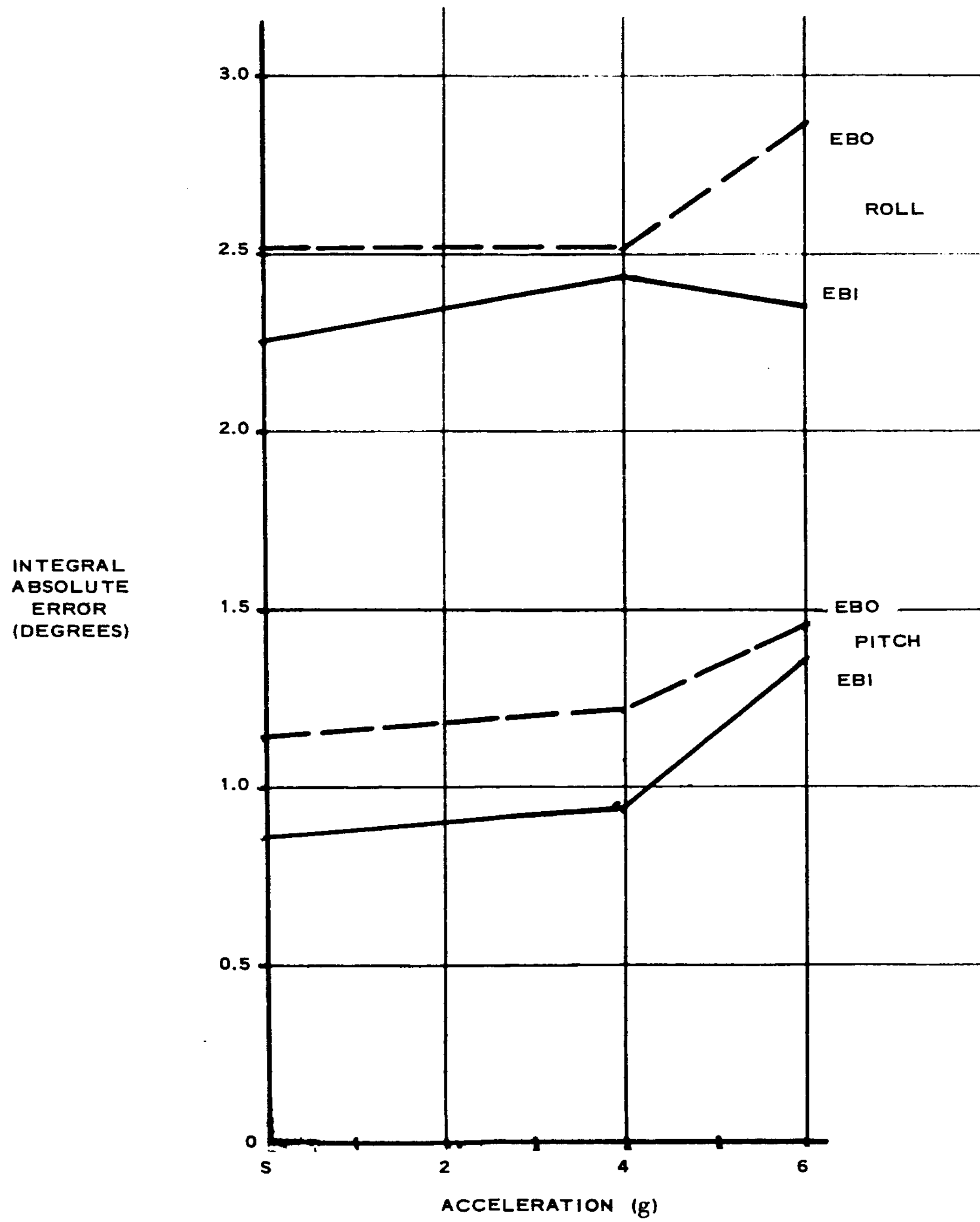


FIGURE 6. TRACKING PERFORMANCE FOR CONTROL CONDITION.

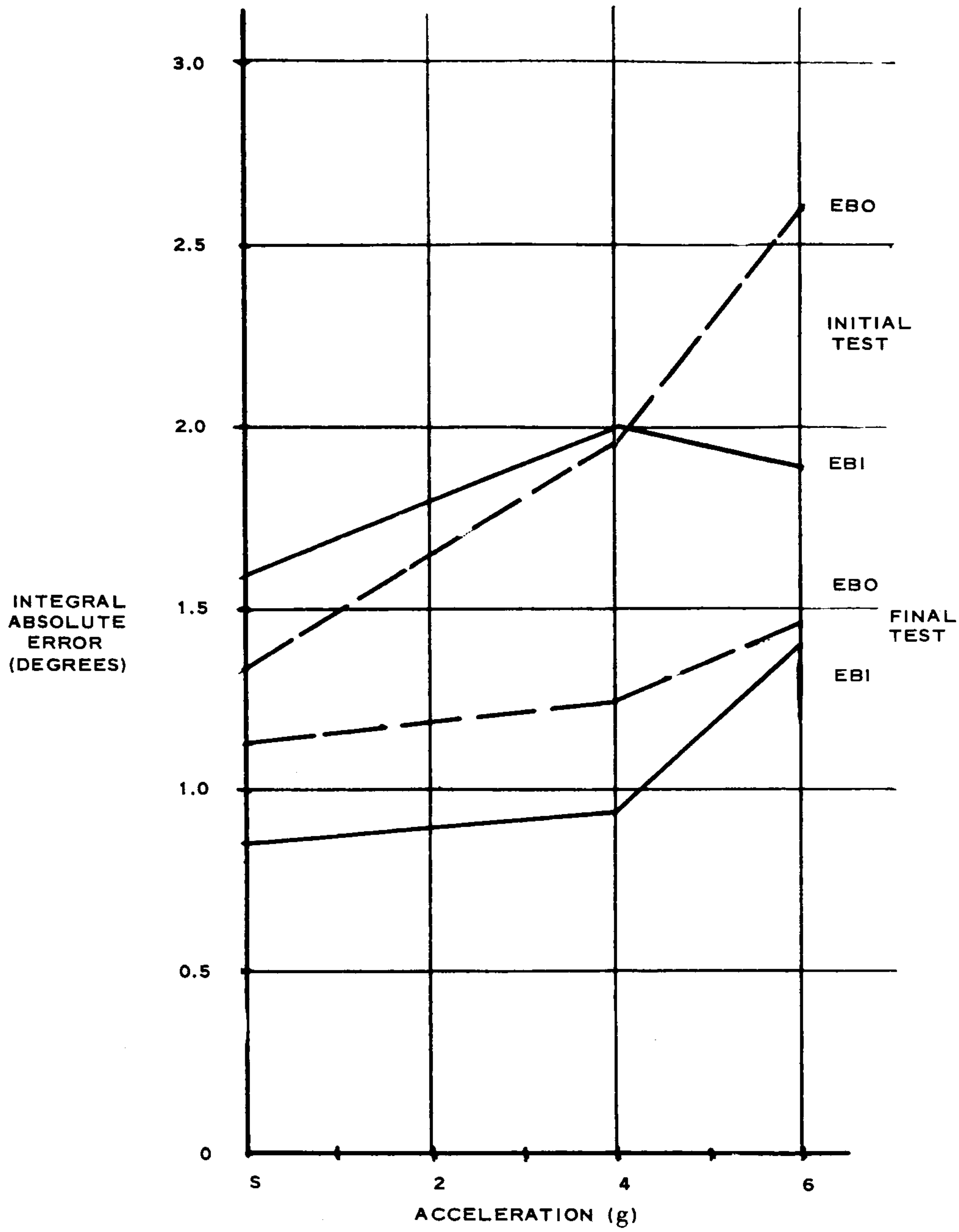


FIGURE 7. LEARNING EFFECTS (PITCH ONLY)

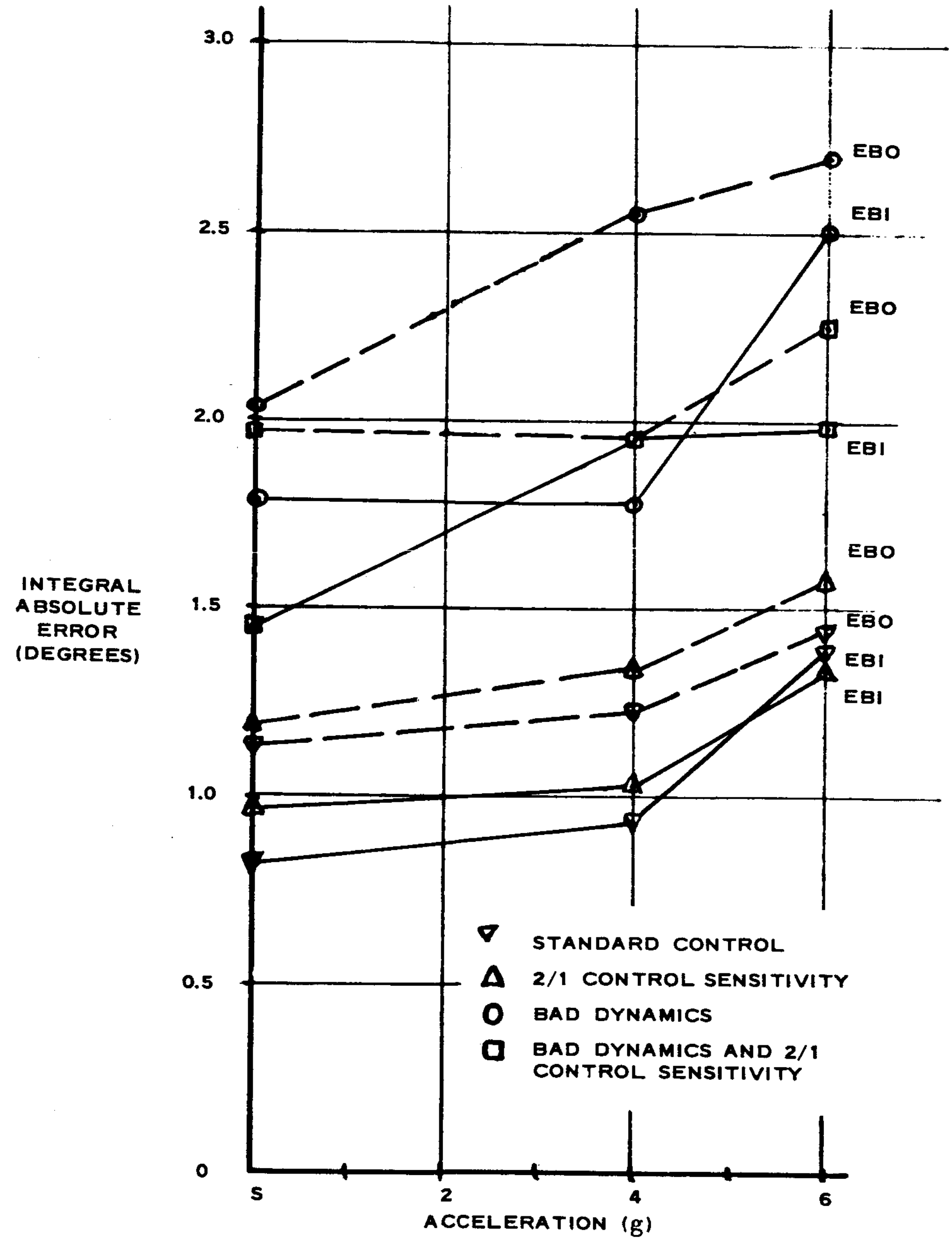


FIGURE 8A. EFFECTS OF CONTROL SENSITIVITY AND DYNAMICS ON PITCH ERROR

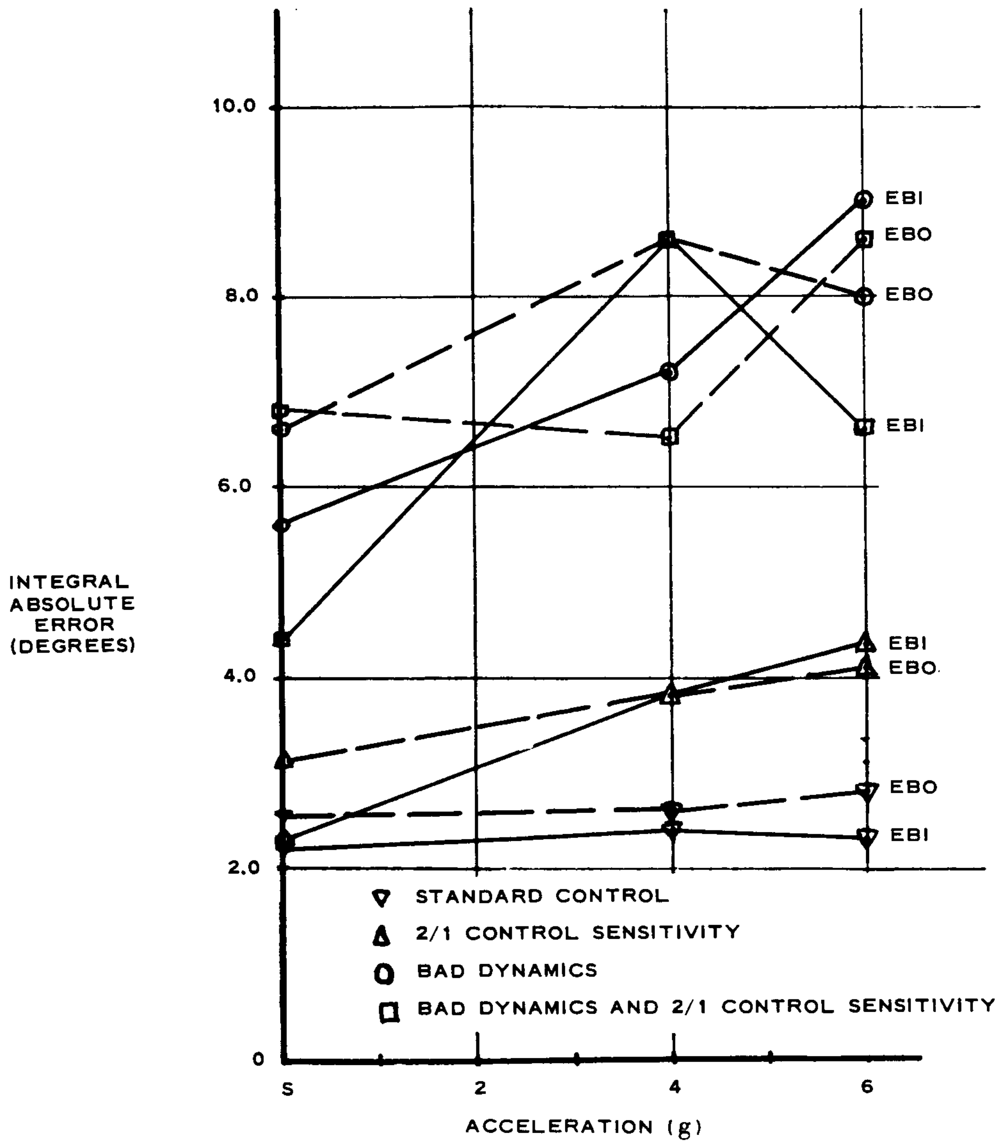


FIGURE 8B. EFFECTS OF CONTROL SENSITIVITY AND DYNAMICS ON ROLL ERROR

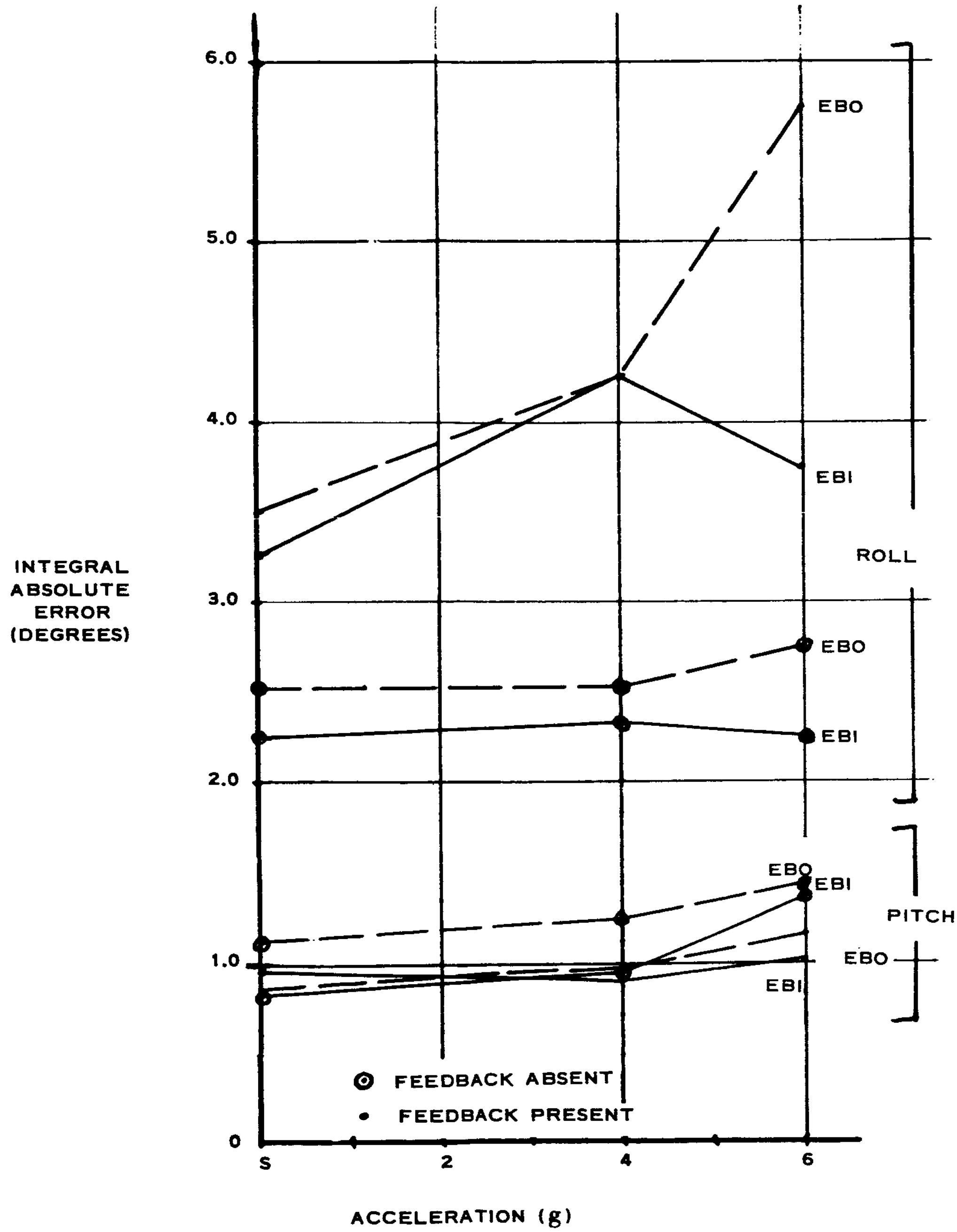


FIGURE 9. EFFECT OF FEEDBACK ON PITCH AND ROLL ERROR

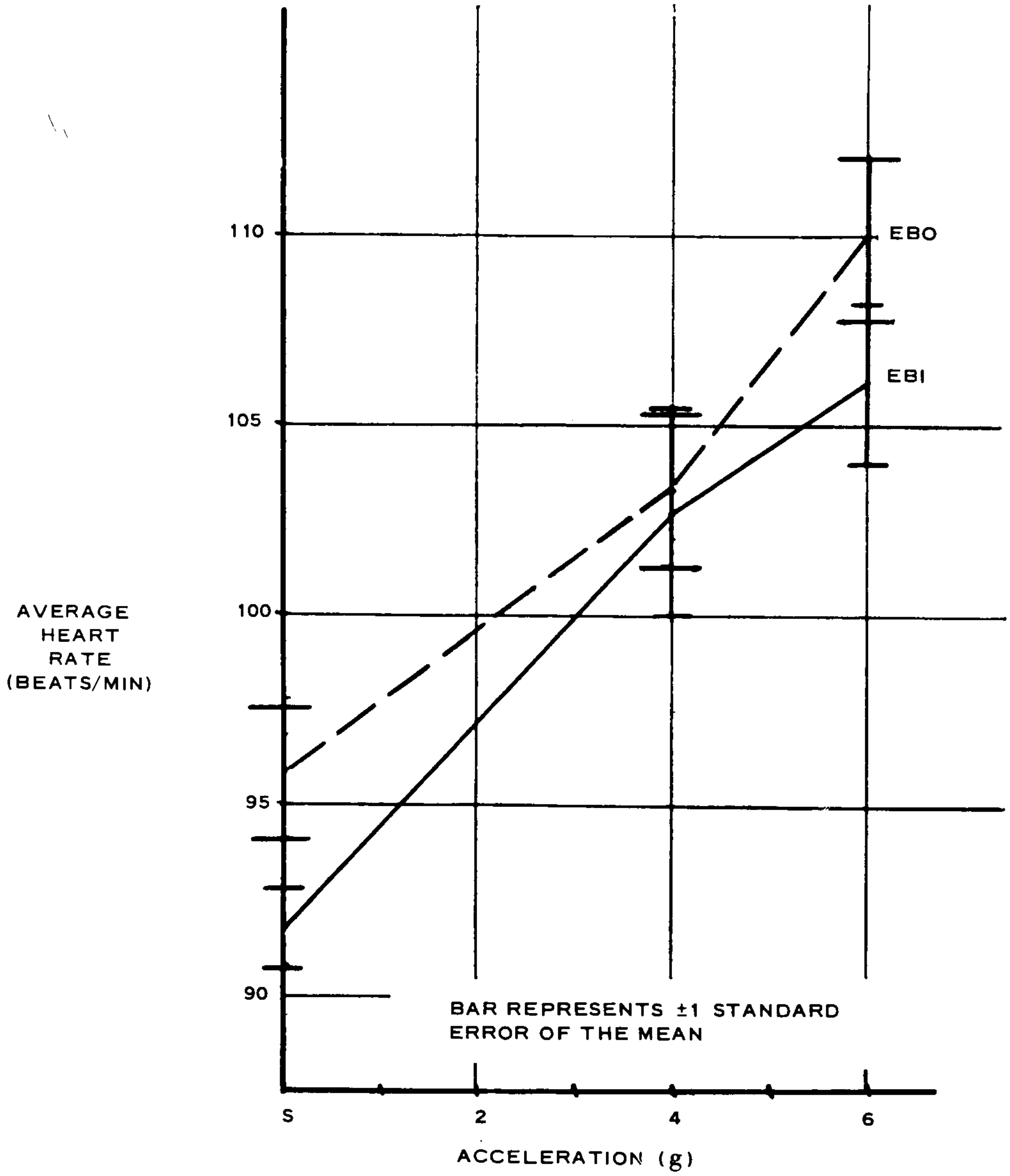


FIGURE 10. THE EFFECT OF ACCELERATION ON HEART RATE

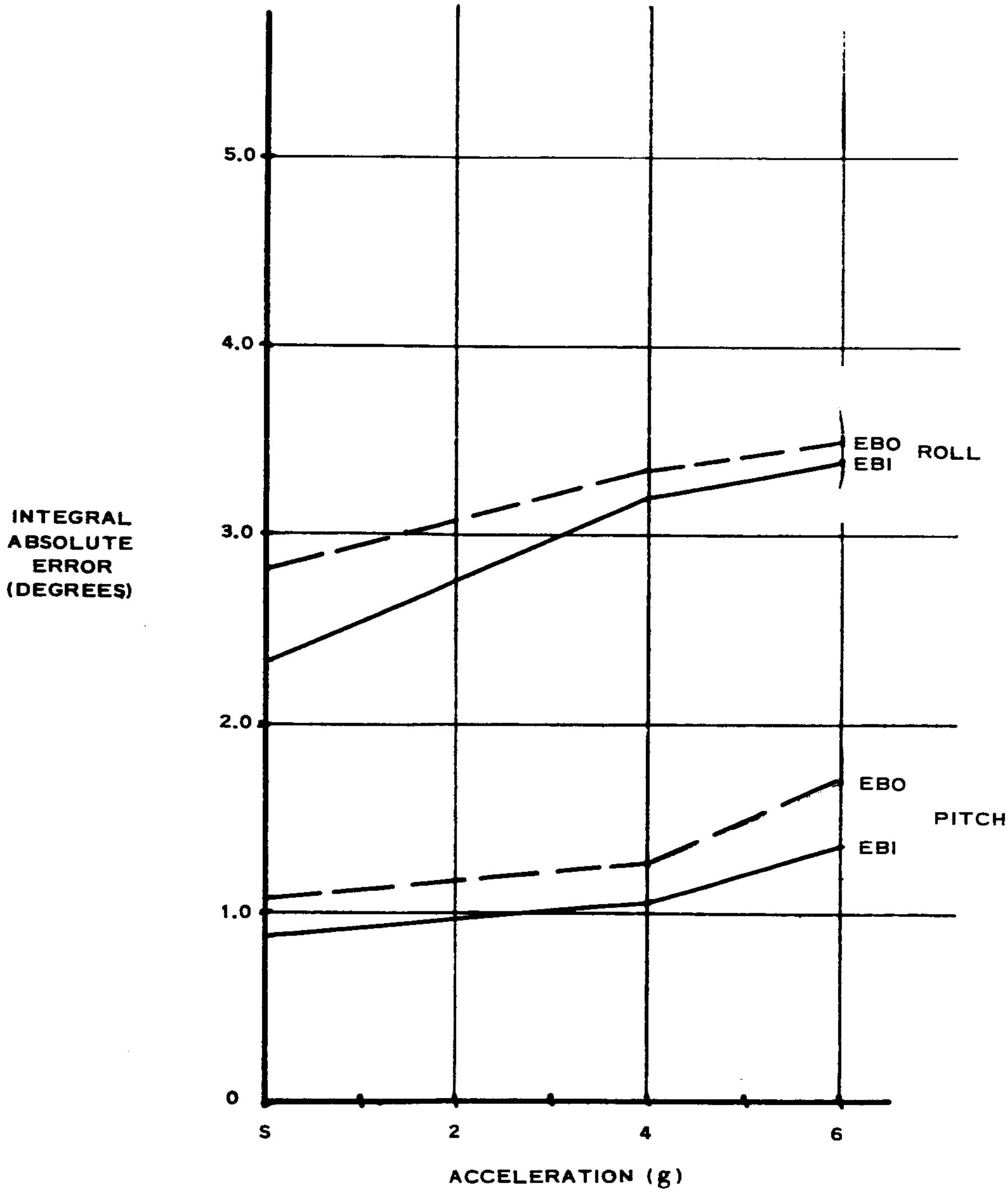


FIGURE 11. POOLED EFFECTS OF DIRECTION OF ACCELERATION

TABLE I

Tracking Performance for Control Conditions

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	2	549 250	4.58	0.05 *
Direction	1	337 080	2.80	N.S.
Interaction	2	64 583	0.54	N.S.
Error	24	119 874		

ANALYSIS OF VARIANCE OF ROLL ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	2	10 365	0.23	N.S.
Direction	1	54 525	1.19	N.S.
Interaction	2	718	0.02	N.S.
Error	24	45 920		

For Tables I thru 5B

*95% probability that the obtained differences are due to the experimental conditions.

**At the 99% probability level.

TABLE 2

Tracking Performance as a Function of Acceleration and Learning Effects

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	921 440	2.35	0.07
Learning	1	8 347 740	21.33	0.01**
A x L	5	383 277	0.98	N. S.
Error	48	391 425		

TABLE 3

Tracking Performance as a Function of Acceleration and Control Stick Pre-load

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	516,581	3.91	0.01**
Preload	1	68,952	0.52	N.S.
Interaction	5	151,732	1.15	N.S.
Error	36	132,090		

Tracking Performance as a Function of Acceleration and Control Stick Force-Displacement Gradient

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	990,598	4.17	0.01**
Spring Constant	1	73,008	0.31	N.S.
Interaction	5	92,673	0.39	N.S.
Error	36	237,283		

TABLE 4A

Tracking Performance as a Function of Acceleration, Vehicle Dynamics and Control System Sensitivity

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	1 407 044	4.10	0.01**
Dynamics	1	22 562 700	65.81	0.01**
Sensitivity	1	413 340	1.21	N.S.
Acceleration x Dynamics	5	164 750	0.48	N.S.
Acceleration x Sensitivity	5	202 994	0.59	N.S.
Dynamics x Sensitivity	1	1 180 830	3.44	N.S.
Acceleration x Dynamics x Sensitivity	5	89 055	0.26	N.S.
Error	96	342 835		

TABLE 4B

Tracking Performance as a Function of Acceleration, Vehicle Dynamics and Control System Sensitivity

ANALYSIS OF VARIANCE OF ROLL ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	843 288	2.07	N.S.
Dynamics	1	32 791 020	79.59	0.01 **
Sensitivity	1	449 580	1.09	N.S.
Acceleration x Dynamics	5	257 746	0.625	N.S.
Acceleration x Sensitivity	5	93 092	0.225	N.S.
Dynamics x Sensitivity	1	1 059 540	2.571	N.S.
Acceleration x Dynamics x Sensitivity	5	213 374	0.517	N.S.
Error	96	412 000		

TABLE 4C

Tracking Performance As a Function of Acceleration (Direction and Magnitude), Vehicle Dynamics and Control System Sensitivity

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration(A)	5	1 407 044	4.655	0.01**
Dynamics(B)	1	22 562 700	16.037	0.05*
Sensitivity(C)	1	413 340	1.198	N.S.
Subjects(d)	4	2 523 252	Not testable	
AB	5	164 730	1.216	N.S.
AC	5	202 994	1.458	N.S.
BC	1	1 180 830	9.809	0.05*
Ad	20	302 220	Not testable	
Bd	4	1 406 898	Not testable	
Cd	4	345 006	Not testable	
ABC	5	89 055	0.469	N.S.
ABd	20	135 432	0.714	N.S.
ACd	20	139 200	0.733	N.S.
BCd	4	120 379	0.634	N.S.
ABCd	20	189 648		

TABLE 4D

Tracking Performance As a Function of Acceleration (Direction and Magnitude), Vehicle Dynamics and Control System Sensitivity

ANALYSIS OF VARIANCE OF ROLL ERROR

Variable	D of F	Mean Square	F-Ratio	Significance
Acceleration(A)	5	843 288	4.397	0.01**
Dynamics(B)	1	32 791 020	49.048	0.01**
Sensitivity(C)	1	449 580	2.939	N.S.
Subjects(d)	4	5 150 616	Not testable	
AB	5	257 746	1.935	N.S.
AC	5	93 092	0.870	N.S.
BC	1	1 059 540	1.614	N.S.
Ad	20	191 750	Not testable	
Bd	4	668 547	Not testable	
Cd	4	152 961	Not testable	
ABC	5	213 374	0.969	N.S.
ABd	20	133 142	0.604	N.S.
ACd	20	106 926	0.485	N.S.
BCd	4	656 418	2.982	0.05*
ABCd	20	220 075		

TABLE 5 A

Tracking Performance as a Function of Acceleration (Direction and Magnitude) and the Presence or Absence of Additional Visual Error Feedback Information.

ANALYSIS OF VARIANCE FOR PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	290,898	2.41	0.05*
Feedback	1	507,840	4.21	0.05*
Interaction	5	103,356	0.85	N.S.
Error	48	120,708		

ANALYSIS OF VARIANCE FOR ROLL ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	5	129,052	0,698	N.S.
Feedback	1	2,683,590	14,53	0.01**
Interaction	5	125,509	0.679	N.S.
Error	48	184,694		

TABLE 5B

Tracking Performance as a Function of Acceleration (Direction and Magnitude) and the Presence or Absence of Additional Visual Error Feedback Information.

ANALYSIS OF VARIANCE FOR PITCH ERROR

Variable	D of F	Mean Square	F-Ratio	Significance
Acceleration(A)	5	290 898	2.38	N.S.
Feedback(B)	1	507 840	8.50	0.05*
Subjects(c)	4	490 974	4.01	0.05*
AB	5	103 356	2.27	N.S.
Ac	20	122 149	2.67	0.05*
Bc	8	59 729	1.31	N.S.
ABc	20	45 464		

ANALYSIS OF VARIANCE FOR ROLL ERROR

Variable	D of F	Mean Square	F-Ratio	Significance
Acceleration(A)	5	129 052	1.29	N.S.
Feedback(B)	1	2 683 590	7.89	0.05 *
Subjects(c)	4	768 630	2.26	N.S.
AB	5	125 509	2.33	N.S.
Ac	20	99 510	1.84	N.S.
Bc	8	340 216	6.31	0.01**
ABc	20	53 943		

TABLE 6 A

MEANS, VARIANCE, AND STANDARD DEVIATIONS OF PILOT RATINGS

Subjects	Mean	Variance	Standard Deviation
S_2	3.266	2.77	1.66
S_3	4.200	1.57	1.25
S_4	3.983	1.37	1.17
S_5	3.800	4.53	2.13
S_6	3.466	1.72	1.31
Total Subjects	3.743	2.51	1.58

TABLE 6B

Spearman Rank Correlation Coefficient (r_s)

Correlation of Pilot Opinion Data With Tracking Performance Scores

Subject #	Correlation Pitch	Roll
2	0.574**	0.658**
3	0.415*	0.510**
4	0.431*	0.495**
5	0.237	0.810**
6	0.499**	0.133

* Obtained r_s must equal or exceed 0.306 to be significant at 0.05

** Obtained r_s must equal or exceed 0.432 to be significant at 0.01

Note: Each value in the above table was based on five conditions identified as follows:

1) Standard Control (Final run)

2) Bad Dynamics

3) 2/1 Control Sensitivity

4) Bad Dynamics and 2/1 Control Sensitivity

5) Visual Error Feedback

Six ratings and six tracking performance scores were compared for each of these five conditions.

TABLE 7

Pooled Effects of Acceleration

ANALYSIS OF VARIANCE OF PITCH ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	2	2 420 946	13.76	0.01**
Direction	1	1 997 568	11.36	0.01**
Interaction	2	44 208	0.25	N.S.
Error	102	175 902		

ANALYSIS OF VARIANCE OF ROLL ERROR

Variable	D of F	Mean Square	F Ratio	Significance
Acceleration	2	255 980	1.50	N.S.
Direction	1	47 040	0.28	N.S.
Interaction	2	21 065	0.12	N.S.
Error	54	170 718		

**99% probability that the obtained differences are due to the experimental conditions.

Appendix 1

SCHEDULE OF RUNS

1st Week

	Thursday	Friday	Monday	Tuesday	Thursday	Friday
1	EBI 12111 EBO 12111		EBO 22111 EBI 22111			EBO 11111 EBI 11111
2			EBI 12111 EBO 12111	EBI 22111 EBO 22111	EBI 11111 EBO 11111	
3		EBI 12111 EBO 12111		EBI 22111 EBO 22111	EBI 11111 EBO 11111	
4		EBI 12111 EBO 12111	EBO 22111 EBI 22111	EBI 11111 EBO 11111		
5						

2nd Week

	Monday	Tuesday	Wednesday	Thursday
1				
2	EBO 12211 EBI 12211	EBI 12121 EBO 12121	EBI 12221 EBO 12221	
3	EBO 12221 EBI 12221		EBI 12211 EBO 12211	
4		EBI 12221 EBO 12221 EBI 12121 EBO 12121		EBO 12211 EBI 12211 EBO 12112 EBI 12112 EBO 12111 EBI 12111
5			EBI 12111 EBO 12111	

Appendix 1

SCHEDULE OF RUNS (Continued)

3rd Week

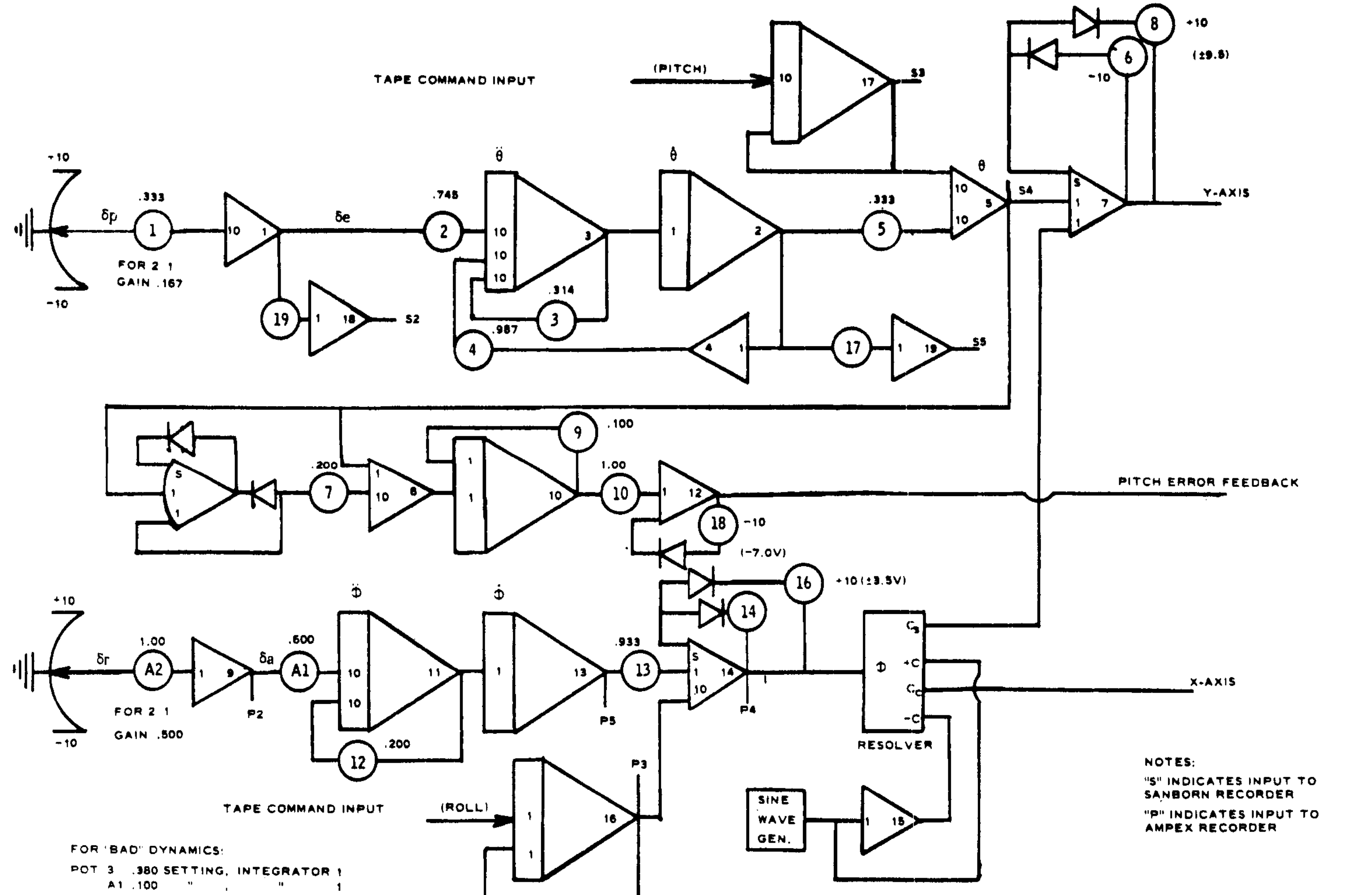
	Tuesday	Thursday
2		EBO 12112 EBI 12112
3	EBI 12121 EBO 12121	
5	EBI 12221 EBO 12221	EBO 12211 EBI 12211

4th Week

	Monday	Tuesday	Wednesday	Thursday	Friday
2	EBI 12111 EBO 12111				
3		EBI 12112 EBO 12112		EBI 12111 EBO 12111	
5			EBO 12112 EBI 12112	EBI 12111 EBO 12111	
6		EBI 12111 EBO 12111	EBO 12211 EBI 12211 EBO 12221 EBI 12221	EBI 12121 EBO 12121	EBI 12112 EBO 12112

Conditions:

EBI or EBO	Direction	Example: EBI 12121
1 or 2	Preload (0.2 lb. or 0.5 lb.)	0.2 lb. preload
1 or 2	Spring Constant (.05 lb/° or 0.2 lb/°)	0.2 lb. spring constant
1 or 2	Dynamics (Good or Bad)	Good Dynamics
1 or 2	Sensitivity (1/1 or 2/1)	2/1 sensitivity
1 or 2	Feedback (without or with)	w/o feedback



FOR "BAD" DYNAMICS:

POT 3	.380 SETTING,	INTEGRATOR	1
A1	.100 " ,	"	1
12	.330 " ,	"	1

NOTES:
"S" INDICATES INPUT TO SANBORN RECORDER
"P" INDICATES INPUT TO AMPEX RECORDER

APPENDIX 2. COMPUTER PROGRAM

Appendix 3a

PILOT RATINGS FOR PITCH

	EBI Static	EBI 4g	EBI 6g	EBO Static	EBO 4g	EBO 6g
Standard Control (Final Test)						
S2	1	1	2	2	2	3
S3	5	4	4	4.5	4	4
S4	4	4	5	4	3	3
S5	2	2	2	2	2	2
S6	3	3	3	3	3	3
Bad Aircraft Dynamics						
S2	6	6	6	6	6	6
S3	5	6	6	7	5	6
S4	5	4	4	5	4	3
S5	7	8	8	6	6	7
S6	5.5	5.5	5.5	5	5	5
2/1 Control Sensitivity						
S2	2	2	2	2	2	2
S3	3	3	2	3	3	2
S4	2	1	2	2	1	3
S5	2	2	3	2	2	3
S6	2	2	2.5	2	2	2.5
Bad Aircraft Dynamics + 2/1 Control Sensitivity						
S2	5	5	5	6	6	6
S3	5	5	4	5	4	5
S4	8	7	7	7	6	6
S5	6	6	6	7	7	8
S6	4.5	4.5	4.5	5	5	5
Visual Error Feedback						
S2	2	2	2	2	2	2
S3	4	3	3	5	4	4
S4	4	3	3	4	3	3
S5	2	3	3	2	3	3
S6	2	2	2.5	2	2	2.5

Appendix 3a (Continued)

PILOT RATINGS FOR ROLL

	EBI			EBO		
	Static	4g	6g	Static	4g	6g
Standard Control						
S2	1	2	2	2	2	2
S3	4	3	3	3.5	3	3
S4	4	5	4	4	2	2
S5	2	2	2	2	2	2
S6	3	3	3	3	3	3
Bad Aircraft Dynamics						
S2	3	3	3	3	3	3
S3	5	5	5	7	5	6
S4	6	5	5	6	5	4
S5	5	6	6	5	5	5
S6	5.5	5.5	5.5	5	5	5
2/1 Control Sensitivity						
S2	3	3	3	3	3	3
S3	3	3	2	3	3	2
S4	2	2	2	3	2	4
S5	2	2	2	2	2	3
S6	2	2	2.5	2	2	2.5
Bad Aircraft Dynamics + 2/1 Control Sensitivity						
S2	5	5	5	6	6	6
S3	6	6	5	5	6	4
S4	5	4	4	5	4	4
S5	4	4	4	6	6	7
S6	4.5	4.5	4.5	5	5	5
Visual Error Feedback						
S2	2	2	2	2	2	2
S3	3	3	3	5	4	4
S4	4	3	3	2	3	3
S5	2	3	3	2	3	3
S6	2	2	2.5	2	2	2.5

Appendix 3b

FRIEDMAN TWO-WAY ANALYSIS OF VARIANCE
FOR ROLL RATINGS

Subject	EBI			EBO		
	Static	4g	6g	Static	4g	6g
2	1	4	4	4	4	4
3	6	2.5	2.5	5	2.5	2.5
4	4	6	4	4	1.5	1.5
5	3.5	3.5	3.5	3.5	3.5	3.5
6	3.5	3.5	3.5	3.5	3.5	3.5
Total	18.0	19.5	17.5	20.0	15.0	15.0

$$\chi_r^2 = \frac{12}{Nk(k+1)} \sum_{j=1}^{k} (R_j) - 3N(k+1)$$

WHERE N = NUMBER OF ROWS
k = NUMBER OF COLUMNS
R_j = SUM OF RANKS IN jTH COLUMN

$$\chi_r^2 = \frac{12}{(5)(6)(6+1)} \left[18^2 + 19.5^2 + 17.5^2 + 20^2 + 15^2 + 15^2\right] - \left[3(5)(6+1)\right]$$

FOR d.f. = 5, $\chi_r^2 = 1.05$ IS NOT SIGNIFICANT

Appendix 3b Continued

FRIEDMAN TWO-WAY ANALYSIS OF VARIANCE
FOR PITCH RATINGS

Subject	EBI			EBO		
	Static	4g	6g	Static	4g	6 g
2	1.5	1.5	4	4	4	6
3	6	2.5	2.5	5	2.5	2.5
4	4	4	6	4	1.5	1.5
5	3.5	3.5	3.5	3.5	3.5	3.5
6	3.5	3.5	3.5	3.5	3.5	3.5
Total	18.5	15	19.5	20	15	17

$$\chi_r^2 = \frac{12}{(5)(6)(6+1)}\left[18.5^2 + 15^2 + 19.5^2 + 20^2 + 15^2 + 17^2\right] - \left[3(5)(6+1)\right]$$

$$= 1.37$$

FOR d.f. = 5, $\chi_r^2 = 1.37$ IS NOT SIGNIFICANT

Appendix 3c

WILCOXON MATCHED-PAIRS SIGNED-RANKS TESTS
AIRCRAFT DYNAMICS

ROLL

Direction	Subj.	Control	Bad Dynamics	d	Rank of d	Less Freq.	Sign.
EBI	S2	1.7	3	1.3			
	S3	3.3	5	1.7			
	S4	4.3	5.3	1.0			
	S5	2	5.7	3.7			
	S6	3	5.5	2.5			
EBO	S2	2	3	1.0			
	S3	3.1	6	2.9			
	S4	2.7	5	2.3			
	S5	2	5	3.0			
	S6	3	5	2.0		T = 0 N = 10	Significance: 0.01

PITCH

Direction	Subj.	Control	Bad Dynamics	d	Rank of d	Less Freq.	Sign.
EBI	S2	1.3	6	5.7			
	S3	4.3	5.7	1.4			
	S4	4.3	4.3	0			
	S5	2	7.7	5.7			
	S6	3	5.5	2.5			
EBO	S2	2.3	6	3.7			
	S3	4	6	2.0			
	S4	3.3	4	0.7			
	S5	2	6.3	4.3		T = 0	Significance:
	S6	3	5	2.0		N = 9	0.01

Appendix 3c Continued

CONTROL SENSITIVITY

PITCH

		Control	2/1 Sen.	d	Rank of d	Less Freq. Sign.
EBI	S2	1.3	2	0.7	4	4
	S3	4.3	2.7	-1.6	-9.0	
	S4	4.3	1.7	-2.6	-10.0	
	S5	2	2.3	0.3	2	2
	S6	3	2.1	-0.9	-5.5	
EBO	S2	2.3	2	-0.3	-2	
	S3	4	2.7	-1.3	-7.5	
	S4	3.3	2.0	-1.3	-7.5	
	S5	2	2.3	0.3	2	2
	S6	3	2.1	-0.9	-5.5	

Significance: 0.05

T = 8
N = 10

ROLL

		Control	2/1 Sen.	d	Rank of d	Less Freq. Sign.
EBI	S2	1.7	3	0.3	2	2
	S3	3.3	2.7	-0.6	-4.5	
	S4	4.3	2	-2.3	-9	
	S5	2	2	0		
	S6	3	2.1	-0.9	-6.5	
EBO	S2	2	3	-1.0	-8	
	S3	3.1	2.7	-0.6	-4.5	
	S4	2.7	3	0.3	2	2
	S5	2	2.3	0.3	2	2
	S6	3	2.1	-0.9	-6.5	

Significance: 0.05

T = 6
N = 9

Appendix 3c Continued

VISUAL ERROR FEEDBACK

PITCH

		Control	Feedback	d	Rank of d	Less Freq. Sign.
EBI	S2	1.3	2	0.7	4	4
	S3	4.3	3.3	-1.0	-8.5	
	S4	4.3	3.3	-1.0	-8.5	
	S5	2	2.7	0.7	4	4
	S6	3	2.1	-0.9	-6.5	
EBO	S2	2.3	2	-0.3	-1.5	
	S3	4	4.3	0.3	1.5	1.5
	S4	3.3	3.3	0		
	S5	2	2.7	0.7	4	4
	S6	3	2.1	-0.9	-6.5	

Significance: N.S.

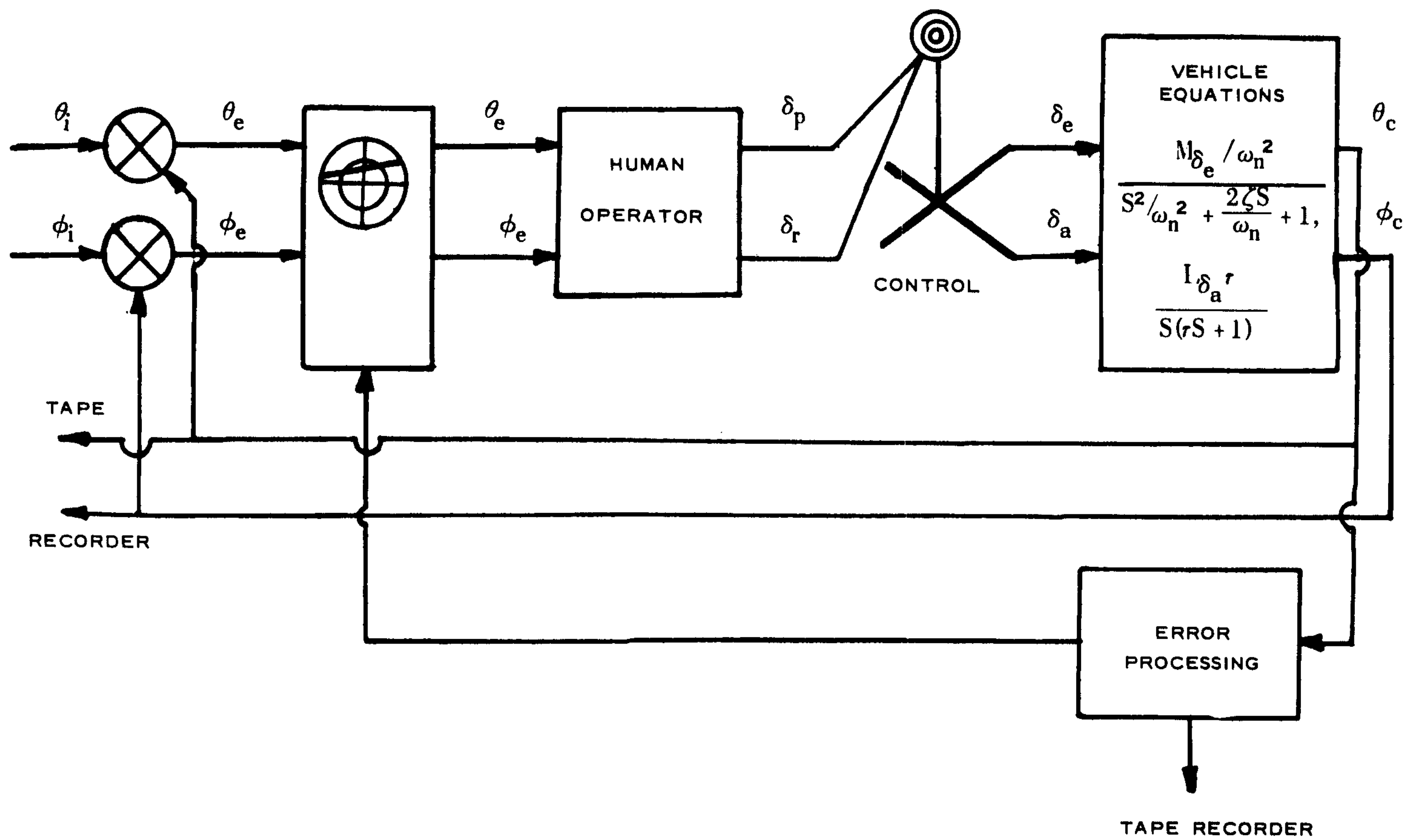
T = 13.5
N = 9

ROLL

		Control	Feedback	d	Rank of d	Less Freq. Sign,
EBI	S2	1.7	2	0.3	1.5	
	S3	3.3	3	-0.3	-1.5	-1.5
	S4	4.3	3.3	-1.0	-8	-8
	S5	2	2.7	0.7	4.5	
	S6	3	2.1	-0.9	-6.5	-6.5
EBO	S2	2	2	0		
	S3	3.1	4.3	1.2	9	
	S4	2.7	3.3	0.6	3	
	S5	2	2.7	0.7	4.5	
	S6	3	2.1	-0.9	-6.5	-6.5

Significance: N.S.

T = 22.5
N = 9



APPENDIX 5. BLOCK DIAGRAM OF EXPERIMENT LAYOUT

	ADJECTIVE RATING	NUMERICAL RATING	DESCRIPTION	PRIMARY MISSION ACCOMPLISHED?	CAN BE LANDED
NORMAL OPERATION	SATISFACTORY	1	EXCELLENT, INCLUDES OPTIMUM	YES	YES
		2	GOOD, PLEASANT TO FLY	YES	YES
		3	SATISFACTORY, BUT WITH SOME MILDLY UNPLEASANT CHARACTERISTICS	YES	YES
EMERGENCY OPERATION	UNSATISFACTORY	4	ACCEPTABLE, BUT WITH UNPLEASANT CHARACTERISTICS	YES	YES
		5	UNACCEPTABLE FOR NORMAL OPERATION	DOUBTFUL	YES
		6	ACCEPTABLE FOR EMERGENCY CONDITION ONLY	DOUBTFUL	YES
NO OPERATION	UNACCEPTABLE	7	UNACCEPTABLE EVEN FOR EMERGENCY CONDITION	NO	DOUBTFUL
		8	UNACCEPTABLE - DANGEROUS	NO	NO
		9	UNACCEPTABLE - UNCONTROLLABLE	NO	NO
	UNPRINTABLE	10	X!@&&&**//#!! DID NOT GET BACK TO REPORT	WHAT MISSION?	

APPENDIX 6. PILOT OPINION RATING SYSTEM (TAKEN FROM COOPER 1957)

APPENDIX 4

LIST OF SUBJECTS

S_1	P. Blum	Test Pilot, Douglas
S_2	S. Reid	Engineering Student
S_3	H.C.Van Valkenburg	Test Pilot, Douglas
S_4	D. Walton	Graduate Student
S_5	J. Yates	Reserve Pilot
S_6	R. C. Innis	Ames Test Pilot

Appendix 7

ERROR SCORES FOR TRACKING TASKS

PITCH

	EBI Static	EBI 4g	EBI 6g	EBO Static	EBO 4g	EBO 6g	
Standard Control- (Initial Test)							12111(1)
Sub. 1	952	793	909	1331	1545	1582	
Sub. 2	1927	2806	2980	1057	3533	4427	
Sub. 3	1184	1350	1170	1299	1019	1862	
Sub. 4	2350	3150	2090	1689	1901	2173	
Sub. 5	1531	1979	2005	1255	1988	3029	
Stick Preload							22111
Sub. 1	988	877	718	884	764	1608	
Sub. 2	943	1915	1216	1034	1608	2379	
Sub. 3	737	792	766	1025	861	1183	
Sub. 5	922	1441	1184	1178	1361	1960	
Stick Spring Constant							11111
Sub. 1	680	610	770	909	1124	1400	
Sub. 2	830	1177	1735	1019	2209	3612	
Sub. 3	775	823	2271	944	1043	1677	
Sub. 5	1031	1181	1778	1067	1072	1213	
Bad Aircraft Dynamics							12211
Sub. 2	2052	1667	1957	1571	2812	3648	
Sub. 3	1208	1466	1565	1820	2531	3061	
Sub. 4	2781	2638	4313	2528	2222	2742	
Sub. 5	1500	1845	3477	2889	3569	2439	
Sub. 6	1287	1145	1186	1245	1674	1583	
2/1 Control Sensitivity							12121
Sub. 2	880	963	1018	1298	1279	1786	
Sub. 3	937	944	1085	867	1298	1702	
Sub. 4	1066	1615	2623	1353	1106	1587	
Sub. 5	1024	957	1148	912	1525	1637	
Sub. 6	1055	641	664	1490	2092	1219	
Bad Aircraft Dynamics + 2/1 Control Sensitivity							12221
Sub. 2	1042	1339	1486	1255	1267	2637	
Sub. 3	1103	2058	1875	1708	1757	2026	
Sub. 4	2272	2645	2937	2732	2458	2369	
Sub. 5	1881	2774	2070	3118	2335	2593	
Sub. 6	1011	1061	1535	1124	1975	1527	

Appendix 7 (Continued) PITCH (Continued)

	EBI			EBO			
	Static	4g	6g	Static	4g	6g	
Visual Error Feedback							12112
Sub. 2	823	1219	1229	956	856	1529	
Sub. 3	593	629	746	659	1003	775	
Sub. 4	1881	1003	1095	1230	1033	1008	
Sub. 5	921	1111	1389	736	1229	1310	
Sub. 6	459	481	562	621	577	1289	
Standard Control (Final Test)							12111(2)
Sub. 2	960	1207	2035	1588	1402	1353	
Sub. 3	703	665	894	988	1503	1744	
Sub. 4	1018	673	908	1387	1066	1321	
Sub. 5	749	1300	2069	783	1249	1532	
Sub. 6	629	762	1062	885	810	1218	
			ROLL				
Bad Aircraft Dynamics							12211
Sub. 2	2568	3229	3064	2253	3863	2378	
Sub. 3	1086	1762	2328	1591	1294	2172	
Sub. 4	1211	1800	3081	1428	1528	1425	
Sub. 5	1211	1300	1765	2394	3164	2048	
Sub. 6	907	754	805	786	884	1929	
2/1 Control Sensitivity							12121
Sub. 2	-	1742	2119	1425	2097	2032	
Sub. 3	541	1038	1219	837	816	976	
Sub. 4	497	835	897	426	785	803	
Sub. 5	800	828	880	731	902	849	
Sub. 6	526	372	322	348	379	447	
Bad Aircraft Dynamics + 2/1 Control Sensitivity							12221
Sub. 2	1697	2098	2663	1506	2095	3112	
Sub. 3	573	3427	1626	1825	3011	2164	
Sub. 4	966	2101	1704	1602	1605	2156	
Sub. 5	1261	2401	1636	2657	2216	2378	
Sub. 6	863	601	700	787	764	893	
Visual Error Feedback							12112
Sub. 2	721	1626	1577	958	1638	1931	
Sub. 3	693	1085	881	797	1132	588	
Sub. 4	836	539	522	601	707	741	
Sub. 5	640	579	692	523	661	839	
Sub. 6	1191	1608	1121	1568	1316	3057	

Appendix 7 (Continued)

ROLL (Continued)

Standard Control (Final Test)	EBI Static	EBI 4g	EBI 6g	EBO Static	EBO 4g	EBO 6g
Sub. 2	837	956	1048	863	769	1074
Sub. 3	608	676	524	722	903	624
Sub. 4	519	504	481	674	607	798
Sub. 5	448	428	581	549	524	593
Sub. 6	429	519	338	371	354	499

12111(2)

Pitch Scale:

1000 = 1^{o} (Average deviation in pitch for a one second interval)

Roll Scale:

1000 = 2.5^{o} (Average deviation in roll for a one second interval)

Note: This appendix contains eight "sets" of data for the pitch mode and five sets for the roll mode. This discrepancy was due to equipment problems which resulted in invalid data being collected for the roll mode for three conditions. The pitch data for these same conditions was determined to be valid and therefore included in the report. Time did not permit repeating the conditions for which roll data was discarded.

Appendix 8

COMMAND SIGNAL: AVERAGE ABSOLUTE INTEGRAL

	Roll		Pitch	
	Volts*	Degrees**	Volts*	Degrees**
1)	1306	3.28	6705	6.71
2)	1590	3.98	8225	8.23
3)	1770	4.43	5551	5.55
4)	1410	3.53	6646	6.65
5)	1702	4.25	5995	6.00
6)	1292	3.23	6984	6.98
7)	1502	3.75	6885	6.89
8)	1263	3.15	8666	8.67
9)	1356	3.40	8077	8.08
10)	1311	3.28	8320	8.32
11)	1246	3.13	11578	11.58
12)	1454	3.63	7949	7.95
13)	1876	4.70	4236	4.24
14)	1303	3.25	8713	8.71
15)	1344	3.35	8815	8.82
16)	1355	3.40	8945	8.95
17)	1311	3.28	3714	3.71
18)	1287	3.23	3605	3.61
19)	1393	3.48	6319	6.32
20)	1413	3.53	3999	4.00
		71.26		139.97
		± 3.56		± 7.00

*Each entry represents the average of twenty-four successive readings where each reading is the absolute integral for a five second period recorded from the FM tapes used to provide the command signal input.

**Average deviation (±) for a one second interval.

NASA-Langley, 1964